ENGINEERS AUSTRALIA

Sydney Division

Monaro Country Group

Glenn Rigden
Chairman,
Sydney Engineering Heritage Committee,
Sydney Division,
Engineers Australia.
PO Box 1389
CHATSWOOD NSW 2057

29 November 2008

Dear Glenn

HISTORIC ENGINEERING PLAQUING NOMINATION
Rock Bolting Development Site- Lambie Gorge Cooma, NSW

The Monaro Group of Engineers Australia is submitting the attached application for consideration under the Australian Historic Engineering Plaquing Program.

In our opinion the site is worthy of national recognition. The site represents a window into our pioneering engineering practices, and the theory, of rock bolting in hard rock for the permanent reinforcement of underground tunnels and caverns. In the process of developing the rock bolting knowledge the engineering discipline of rock mechanics became a specialist practice. Both the rock bolting practice and the study of rock mechanics was taken up internationally by being shared through universities, learned societies and via the tunnelling achievements of the major international construction contractors engaged in the Snowy Mountains Scheme.

Many personnel, as employees of the Snowy Mountains Hydro-Electric Authority in both engineering and scientific fields of expertise, contributed successfully to the full development of the engineering pursuit of rock bolting. This work took place in the late 1950's and early 1960's and it was a first for Australia and the world.

The attached information, demonstrates that the Rock Bolting Development Site – Lambie Gorge, Cooma - is unique and of great importance in the history of engineering.

If you require more information relating to the application please do not hesitate to contact the Group's Sub-Committee Chair Mr Walter Mills on 02 6452 7321(h) or the Group's Chair Mr David Byrne on 02 6450 1750(w).

Yours faithfully

Walter B Mills, BE(Elec)
MIEAust CPEng NPER

Alan Hall, BE(Hons), MEngSc
MIEAust CPEng

David Byrne, BE(Civil)
MIEAust CPEng NPER

Rock Bolting Heritage Sub-Committee, Monaro Group, Sydney Division, Engineers Australia.

ENGINEERS
AUSTRALIA

HISTORIC ENGINEERING PLAQUING NOMINATION

ROCK BOLTING DEVELOPMENT SITE
- LAMBIE GORGE COOMA, NSW -

Submitted by:

Engineers Australia Monaro Country Group

November 2008

INTRODUCTION

At the Lambie Gorge experimental site in Cooma NSW we have the opportunity to draw public attention to the significant contribution that has been made from the development of rock bolting engineering to society in Australia and internationally. It achieved greatly improved safety for the miners in such tunnels, gave significantly higher tunnelling speeds, and greatly reduced the overall cost of tunnelling in hard-rock.

Engineers, scientists, technicians and managers, working for the Snowy Mountains Hydro-Electric Authority (SMHEA) in NSW Australia, established a new engineering achievement of hard-rock tunnelling for the world.

This was done in the period 1956 to 1962. A select number of their employees, identified in this Nomination, gave leadership, analysed the criteria, and developed the engineering theory for rock mechanics in order to transform the existing rock bolt usage from a suspension of tunnel ceilings into a fully integrated engineering design with the exposed rock of the tunnel excavation. Its final stage was to move from just a temporary system to achieve a permanent tunnel support system, even in water-filled, rock-exposed tunnels.

This new rock bolting theory and practice was immediately taken up world-wide and it has been noted to be in continuing practice today with only minor extra refinements.

The resulting pride of others engaged on the landmark hydro-electric project at the time as a direct consequence of the renewed interest in the rock bolting development can today be shared and conveyed to the general community at this Lambie Gorge site, otherwise the new rock bolting achievement is all out of sight and out of mind.

The engineering profession may also thereby, register this significant engineering development heritage in the practice of engineering for hard-rock tunnelling.

Walter B Mills, BE(Elec) MIEAust CPEng NPER.
Alan Hall, BE(Hons) MEngSc MIEAust CPEng.
David Byrne, BE(Civil) MIEAust CPEng NPER.

Rock Bolting Heritage Sub-Committee of Monaro Country Group, Engineers Australia.

CONTENTS

PLAQUE NOMINATION FORM

The Administrator,
Engineering Heritage Australia,
Engineers Australia.
Engineering House
11 National Circuit
BARTON ACT 2600

Name of work: ROCK BOLTING DEVELOPMENT SITE, LAMBIE GORGE, COOMA

The above-mentioned work is nominated to be awarded a **National Engineering Landmark** (*if deemed appropriate*).

Location of the Rock Bolting Development Site:

Latitude 36 14; Longitude 140 07; Easting 690 000 to 690 175; Northing 5986 750 to 5987 050; Lot 3 of D.P. 704165 Sheet 1 Registered 30 October 1984 as attached in Appendix A. The Lot 3 has an area of 1.042ha. An aerial map copy (colour) of the curtilage area of the site overlaid with individual property boundaries is attached in Appendix A.

Owner of the Rock Bolting Development Site:

State Government as Crown Land dedicated for Environmental Protection by NSW Government Gazette No 145 dated 25 October 1985 (extract copy attached in Appendix B).

The Department of Lands Goulburn Office has been advised of the nomination of the site as of being highly significant national engineering heritage value.

Whilst no formal Ngarigo Aboriginal Nation Land Council exists, there are a number of matriarchal Elders who are the traditional custodians of the whole of the Monaro tablelands. The Cooma Aboriginal Reconciliation Committee (voluntary, and informal), 1997-2005, facilitated the recent public interest in the Lambie Gorge Crown Land. It was an opportunistic interest to give exposure of their culture through construction of a walking path to a lookout within the Reserve, passing the Rock Bolting Development Site at its downstream entrance end.

The Elders have recognised this engineering heritage site within their ancient family camping area (of pre-European occupation time), but it can be noted that it is not a sacred site – there are no markings, no songs and no art works that have established a particular identity and continuity with the Reserve.

There is no conflict of interest with the Ngarigo descendants today, but there is mutual respectful support. This is demonstrated in the Brochure "Lambie Gorge Walking Track" issued at its official opening in 2006 – that includes a description and map of the Rock Bolting Development Site – see Appendix B.

Access to the Rock Bolting Development Site:

The public walking access to the Site is from the Snowy Mountains Highway on the right bank of Cooma Back Creek, walking upstream through a succession of Reserves held by Cooma-Monaro Shire Council. These Reserves are via the Southern Cloud Memorial Park, the grounds of Cooma Showgrounds, (Reserve R530003), the Cooma Bowling Club (Reserve R85193) and two dedicated right-of-

carriageways along the high bank of the Creek (Reserve R97968). These right-of-carriageway lands may be identified on D.P. 704165 Sh 1.

Alternative access to the Site is via the dedicated land for the aged care facility, known as the Sir William Hudson Memorial Centre. This access is via the top of the Gorge down an Aboriginal heritage track and stone staircase with handrail that were established in 2006 – refer D.P. 788869.

Vehicular access is only possible via private land, at present only partly built on and unfenced, on which Cooma Bowling Clubhouse is built and operates. This land may be identified on D.P. 704165 Sh 1, as Lot 2.

Future Care of the Rock Bolting Development Site:

In order that the present effort of the Rock Bolting Heritage Sub-Committee was not wasted and features of the site were not degraded through neglect in future years, an Overall Management Plan was prepared in 2006 before any effort was expended in preparing the Nomination for State Heritage recognition the following year.

The Overall Management Plan has five principle parts: Management Plan, Conservation Plan, Business Plan, Plaquing and Tourism Plan, and Update Plan for this Management Plan. Refer to Appendix C for a copy of the Overall Management Plan.

Documentation of Claim to Uniqueness of the Rock Bolting Development:

The following documents are provided with this Nomination for reference purposes:-

- American Society of Civil Engineers, Power Division Symposium on underground power stations, October 1957, New York, USA "Snowy Mountains Scheme T1 PS Rock Behaviour and rock bolt support in large excavations" by T. A. Lang, Associate Commissioner Snowy Mountains Hydro-Electric Authority, Cooma – see Appendix D.

- Application for listing on NSW State Heritage Register complete with attachments and photographs– see Appendix E.

- Text and handout copy of slides of Public Lecture "Engineering History in Cooma Rock", researched, prepared and presented by Walter B Mills to Engineers Australia's advertised meetings in Sydney, Cooma, Canberra, Hobart and Townsville (in period 2007-8), complete with Reference List of sources. It is in the lecture that particular reference is made to the individual personnel closely associated with the rock bolting development and rock mechanics as an engineering discipline in its own right– see Appendix F.

- Personal correspondence and photographs from Mr Berle Blehm, USA, (2008) who was responsible for the Contract supervision of installation for the final form of the SMA rock bolting in the major tunnels and caverns of Tumut 2 underground power station– see Appendix G.

Requirements for Signs and Plaques for the Rock Bolting Development Site:

The nature of the rock bolting development site makes it only suitable for interpretive signs and plaques, thus any unanchored rock bolt component metallic parts or documents need to be located in adjacent indoor museums or information/visitor centres. These signs can be mounted on the natural flat rock faces that are at the principal rock bolting experimental site for pull-out tests.

Two signs are required to explain and give interpretation to the Site and its significance; one of text and the other of a drawing of the final form of the SMHEA rock bolt. Copies of these signs are given in Appendix H.

The proposed wording for the Plaque submitted in this Nomination for the consideration of the Plaquing Sub-Committee is given in Appendix H.

Because the public access will come principally in one direction, it is proposed that there be direction signs along the route identifying the significant engineering heritage site location. Such information already exists on published tourist maps available at Information/Visitor Centres in the town.

Nominating Body:

Rock Bolting Heritage Sub-Committee, Monaro Country Group, Engineers Australia

[signature] ....Chair of Nominating Body

Date: 1/12/08

....

Chair of Division Engineering Heritage Group

Date: ....

LOCATION MAP

COPY OF THE PARISH MAP EXTRACT

PLAQUING NOMINATION ASSESSMENT FORM

1. BASIC DATA

Item Name: Rock Bolting Development Site.

Other Names: Lambie Gorge, Cooma, recreational reserve.

Location: Latitude 36 14; Longitude 140 07; Easting 690 000 to 690 175; Northing 5986 750 to 5987 050; Lot 3 of D.P. 704165 Sheet 1 Registered 30 October 1984 as attached in Appendix A. The Lot 3 has an area of 1.042ha. An aerial map copy (colour) of the curtilage area of the site overlaid with individual property boundaries is attached in Appendix A.

Town & State: Cooma, NSW, Postcode 2630.

Local Govt. Area: Cooma Monaro Shire.

Owner: State Government as Crown Land dedicated for Environmental Protection by NSW Government Gazette No 145 dated 25 October 1985 (extract copy attached in Appendix B).

Current Use: Recreational area, dedicated for environmental protection.

Former Use: Engineering and scientific research in connection with the construction of the Snowy Mountains Scheme under the Snowy Mountains Hydro-Electric Authority.

Designer/Builder of Development Site: Snowy Mountains Hydro-Electric Authority.

Year Started: 1956 **Year Completed:** 1962

Physical Description: (extract from page 2 of NSW Data)

Physical Condition: (extract from page 2 of NSW Data)

Modifications and Dates: (extract from page 2 of NSW Data)

Historical Notes: (extract from pages 3 to 6 of NSW Data)

Heritage Listings (information for all listings)

Name: State Heritage Register.
Title: Rock Bolting Development Site – Lambie Gorge Cooma.
Number: n/a
Date: submitted 30 October 2006.

Name: Cooma-Monaro Heritage List (LEP Plan).
Title: Rock Bolting Development Site – Lambie Gorge Cooma.
Number: n/a
Date: submitted 30 October 2006 LEP to be gazetted 2009.

APPLICATION OF HERITAGE ASSESSMENT CRITERIA

APPLICATION OF CRITERIA	
Historical significance SHR criteria (a)	The work undertaken at this site is the genesis of the applied science of rock mechanics and its further international development.
Historical association significance SHR criteria (b)	The site has a special association with SMHEA and through its personnel by technical presentations and by the major tunnelling contractors to an international engineering fraternity. It inspired the organisation to achieve excellence in the whole development of the Scheme.
Aesthetic significance SHR criteria (c)	A high degree of creative and lateral thinking by the personnel involved led to a quantum leap in the development in the science, savings in the Scheme costs, improvement in safety and the speed of tunnelling.
Social significance SHR criteria (d)	Rock bolting is regarded as the most significant engineering development made on the Snowy Scheme. There were fewer tunnelling accidents from post excavation rock falls, giving rise to close-knit team work by a shift crew working months on end for approximately a two year span.
Technical/Research significance SHR criteria (e)	The site gives a window to appreciate what is concealed of the successful engineering of more than 100 km of tunnels and many huge underground caverns. Ample inspiration is available to fully establish the precedence of the SMHEA work and its impact in the engineering fraternity worldwide. The pre-SMHEA work on roof anchors from which the rock bolting development came is documented, in part, in the bibliography of Attachment 3. It is also available to a large extent in Box 30 of D G Moye's papers, ref Doc. 9.1
Rarity SHR criteria (f)	This was the first pioneering site where such activity was undertaken and there is no other similar site anywhere in the world.
Representativeness SHR criteria (g)	The rock in Lambie Gorge is the closest representation of the rock types encountered on the Scheme sites and is fortunately located adjacent the SMHEA laboratory site. Rock bolts in service are not available to view by the general public, but their story of Australian creativity needs to be told from this site.
Integrity	The site retains many of the bolts and drilled holes that were the original field tests.

ROCK BOLTING DEVELOPMENT SITE PHOTOGRAPHS

Curtailage View of the Site – Lambie Gorge
(original laboratory building centre background)

ROCK BOLTING DEVELOPMENT SITE PHOTOGRAPHS

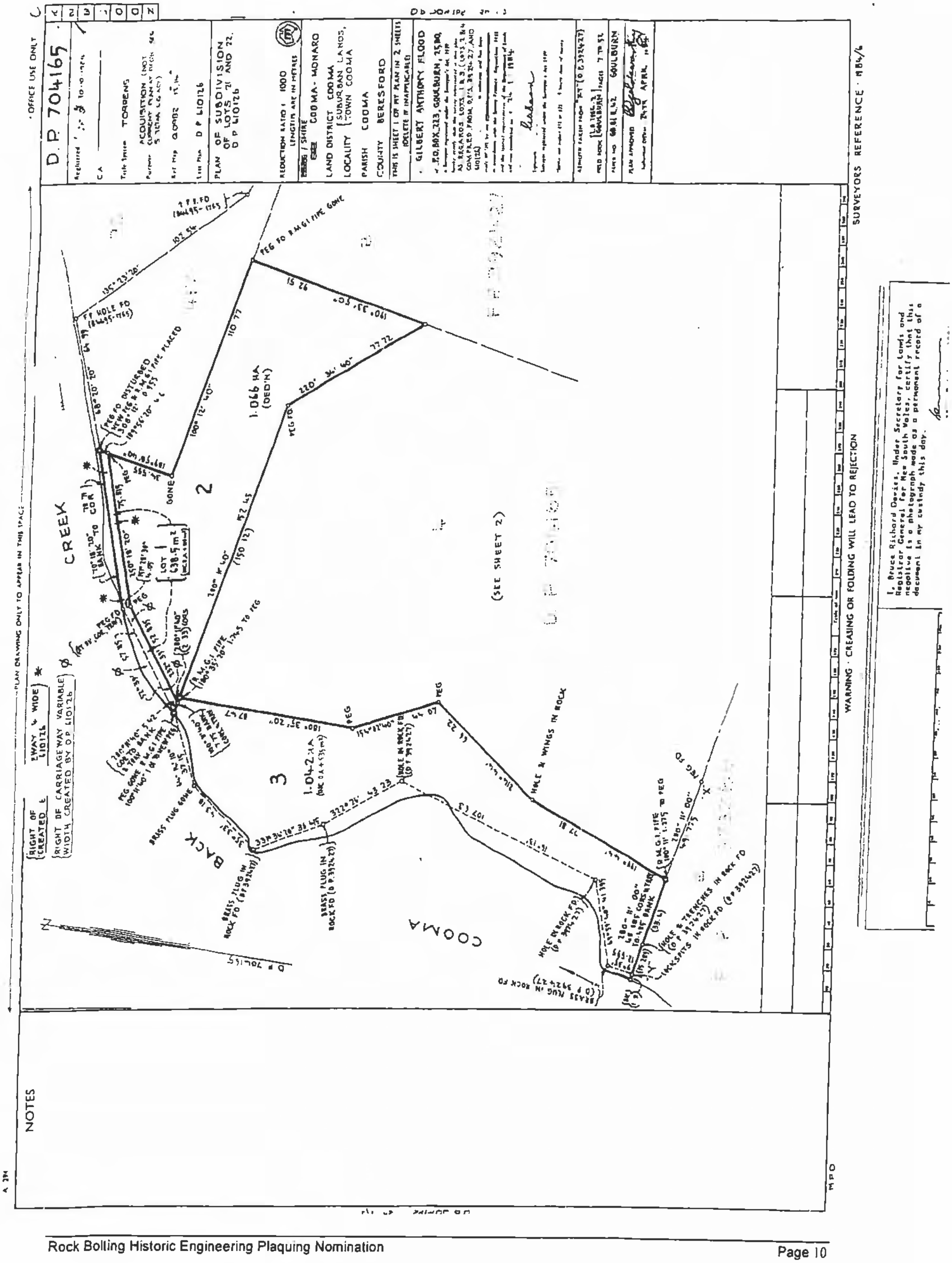
Main rock bolting experimental site – drill holes, rock bolt remnants and information boards with viewing area in the foreground.

APPENDIX A – LOCATION REFERENCES

1 Deposited Plan704165

2 Aerial Map of the curtilage area of the site overlaid with individual property boundaries.

APPENDIX A – LOCATION REFERENCES (1)



APPENDIX A – LOCATION REFERENCES (2)

APPENDIX B – OWNERSHIP REFERENCES

1. NSW Government Gazette no 145 dated 25 October 1985 (extract).

2. Department of Lands DP Identifier issued 12/03/2004.

3. "Lambie Gorge Walking Track", Cooma Reconciliation Committee, 2006.

APPENDIX B – OWNERSHIP REFERENCES (1)

NSW Gazette No 145

25th October, 1985.

RESERVES FROM SALE

In pursuance of the provisions of section 28, Crown Lands Consolidation Act, 1913, I declare that the Crown lands described hereunder shall be reserved from sale for the public purposes specified and such lands are reserved accordingly.

JANICE CROSIO, Minister for Natural Resources.

FOR ACCESS

Land District—Bathurst; Shire—Evans

No. 97959, Parish Rockley, County Georgiana, 1.143 hectares, being lot 246 in D.P. 705343. OE83 H 618.

Land District—Condobolin; Shire—Lachlan

No. 97962, Parish Murga, County Cunningham, 85.4 hectares, being lot 71 in D.P. 720556. OE84 H 186.

FOR PUBLIC RECREATION

Land District—Bathurst; Shires—Evans and Rylstone

No. 97960, at Sofala, Parishes Sofala, Waterbeach and Cunningham, Counties Roxburgh and Wellington, about 875 hectares, being area bounded by lots 168 and 169, D.P. 257544, Turon River, portion 70 and easterly prolongation of northern boundary of that portion to Turon River, Hill End-Sofala road (in Parish of Cunningham); portions 5, 33 and 94 (all in Parish of Waterbeach); portions 293, 519, 520, 528 and 532, area bounded by portion 519, Pennyweight Flat Creek, portion 258, again by Pennyweight Flat Creek and Turon River, area bounded by portions 366, 136, 9, 536, 11 again 536, by the southeasterly prolongation of southwestern boundary of portion 536 to portion 538, by portions 538, 293, 292, 528, 510, 577 and 237, by northerly prolongation of eastern boundary of portion 237 to portion 280, by portion 280 and then Turon River to point of commencement exclusive of portions 13 to 20 inclusive, 22 to 26 inclusive, 28, 91, 175, 216, 234, 295, 310, 365, 379, 380, 490, 491, 493, 494, 501, 550 to 556 inclusive, 560, 567 to 570 inclusive, 575, Reserve 87134 for Resting Place notified 11th April, 1969 and public road, area bounded by portions 10 (Parish of Waterbeach), 544, 513, 515, 529, 508, 537, end of road, portion 531, Trunk Road No. 54, allotment 7 of General Cemetery, R.16934 for Plantation notified 14th January, 1893, northerly prolongation of western boundary of that Reserve No. 16934 to section 8, section 8, R. 84296 for Rubbish Depot notified 19th July, 1963, section 13, Proclaimed Town boundary of Sofala extending westerly, northerly and again westerly to Turon River, and by Turon River and Tanwarra Creek to the point of commencement exclusive of portions 21, 102 to 104 inclusive, 127 and 545 and public road (all in Parish Sofala). OE85 R 23.

NOTE: The following included reserves are hereby revoked: R.75884 for Public Recreation and Access notified 8th May, 1953 and 17th September, 1976, R.90748 for Future Public Requirements notified 7th April, 1977 (Parish of Waterbeach); R. 67468 for Resting Place notified 1st April, 1938 (Parish of Cunningham); R.79898 for Future Public Requirements notified 13th September, 1957, R.80032 for Future Public Requirements notified 27th September, 1957, R.91984 for Future Public Requirements notified 21st March, 1980 and R.94764 for Future Public Requirements notified 15th May, 1981 (all in Parish of Sofala).

It is not intended to revoke the following included reserves: R.65227 for Water Supply and Camping notified 3rd May, 1935 (Parish of Waterbeach); R.11619 for Water Supply and Camping notified 7th June, 1890, R 45816 for Rifle Range notified 28th September, 1910, R.97843 for Future Public Requirements notified 19th July, 1985 (all in Parish of Sofala).

Land District—Bathurst; Shire—Evans

No. 97961, at Wattle Flat, Parishes Sofala and Wiagdon, County Roxburgh, about 305 hectares being portions 158, MT 2, GL 172, GL 185, GL 196, GL 207, GL 215, GL 216, GL 218, GL 219 and GL 233, area bounded by portions 65 and 219, Trunk Road No. 54, portions 305, 66, again 305, 63, 61, 62, road, portion 485 and road to point of commencement, area bounded by portions 496 and 492, end of road, portion 503, end of road, portion 402, end of road, portion 171, end of road, portions 484, 51, 50 and 49, Trunk Road No. 54, portion 311, again Trunk Road No. 54, proclaimed boundary of suburban lands of Village of Wattle Flat westerly and southwesterly to portion 227 (Parish of Wiagdon), by that portion 227, road adjoining the generally southeastern boundaries portions 320 (Parish Wiagdon), 534, 392, again 534 and 499, public road adjoining portions 389 and 42, road west of portion 156, road north and west of portion 496 to point of commencement exclusive of portion 153, area bounded by portions 316, 405, 317, road northwest of portions 162, 173, 88 and part 161, end of road adjoining southeastern boundary of portion 235, portion 235 and Big Oaky Creek to point of commencement, all in Parish of Sofala; area bounded by portions 83 and 82, Public Watering Place No. 323 Gazette 16th December, 1898, end of road, portions 139 and 307, end of road, portions 43, 186, 316, 340, 123 and 51, Trunk Road No. 54, portion 169, again Trunk Road No. 54, portions 52, 53 and 54, Trunk Road No. 54, portion 24, Trunk Road No. 54, portions 272 and 273, end of road, portions 274, 229 and 227 and by proclaimed boundary of suburban lands of Village of Wattle Flat easterly to point of commencement exclusive of portions 198, 225 and 261 and road Parish of Wiagdon. OE85 R 24.

NOTE: It is not intended to revoke the affected part of R.82579 for Water Supply notified 20th May, 1960.

FOR FUTURE PUBLIC REQUIREMENTS

Land District—Braidwood; Shire—Tallaganda

No. 97971, Parish Braidwood, County St Vincent, 1 770 square metres, being allotments 26 and 27, section 15, Town of Braidwood. GB84 H 632

NOTE: R.89562 for Public Buildings notified 25th August, 1975 is revoked.

Land District—Lake Cargelligo; Shire—Lachlan

No. 97969, Parish Whoyeo, County Dowling, 27.80 hectares, being portions 71 and 72. OE80 H 3081 and OE81 H 265.

FOR RESTING PLACE

Land District—Molong; Shire—Cabonne

No. 97972, Parish Warraberry, County Gordon, about 4.047 hectares, being area bounded by portions 50, 33 and 67 and Main Road No. 234. OE85 R 35.

FOR ENVIRONMENTAL PROTECTION

Land District—Cooma; Shire—Cooma-Monaro

No. 97968, Parish Cooma, County Beresford, about 1.042 hectares, being lot 3 of D.P. 704165. GB85 H 496.

FOR REST PARK AND PRESERVATION OF TREES

Land District and Shire Inverell

No. 97963, Parish and Village Little Plain, County Murchison, about 1.66 hectares being section 2 exclusive of allotment 1, but inclusive of lane. AE85 R 43.

NOTE: The whole of the unnotified Reserve for Public Buildings is hereby revoked.

FOR PUBLIC RECREATION (SPEEDWAY)

Land District and Shire—Inverell

No. 97964, Parish Inverell, County Gough, 12.94 hectares, at Inverell, being lot 616 in D.P. 41796. AE85 R 16.

NOTE: The whole of R.96253 for Future Public Requirements, notified 20th August, 1982, is hereby revoked.

FOR BUSHFIRE BRIGADE PURPOSES

Land District—Dubbo; Shire—Narromine

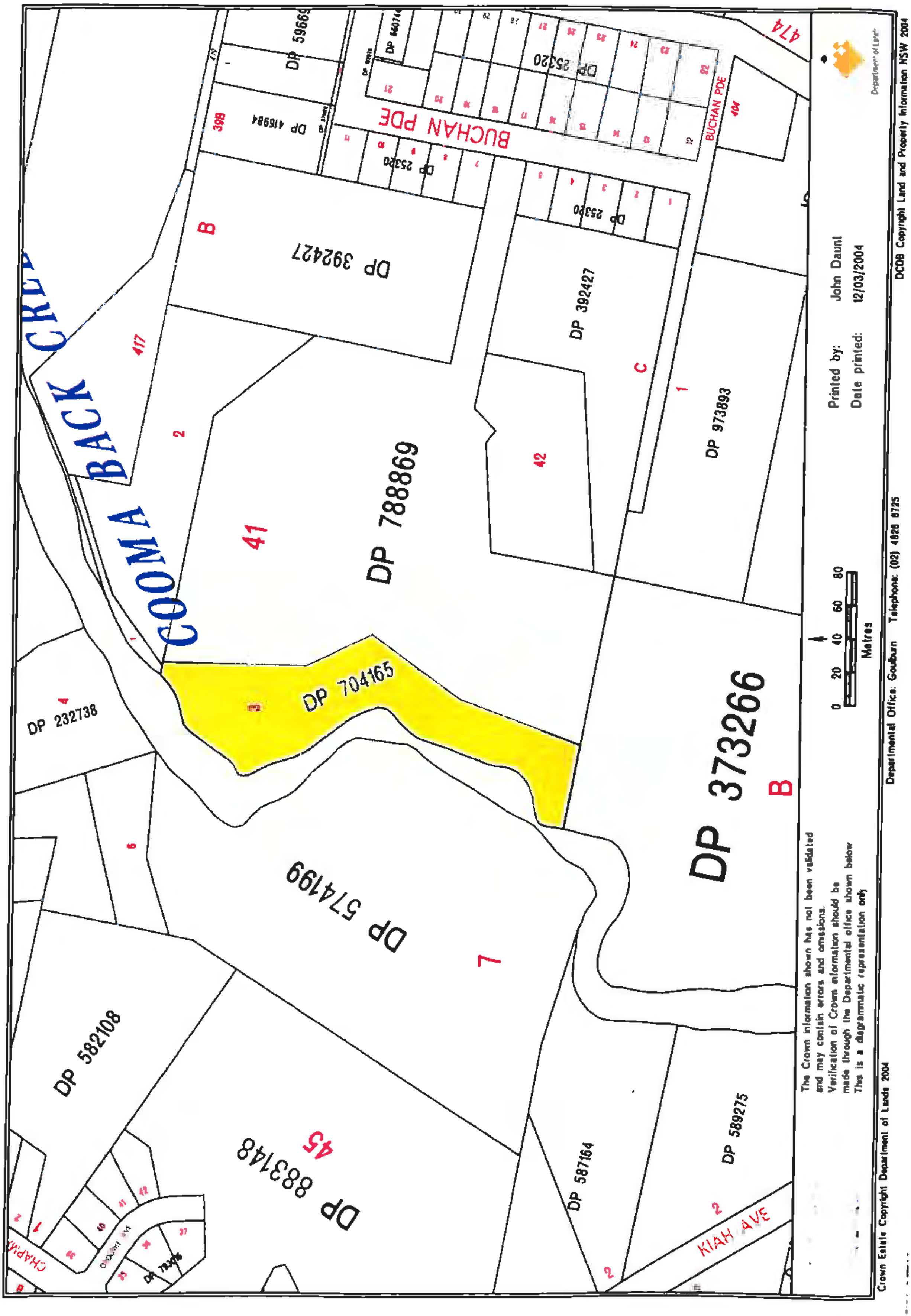
No. 97965, Parish Gundong, County Narromine, 199.8 square metres, being lot 1 in D.P. 720300 at Tomingley. DB84 R 43.

FOR PUBLIC POUND

Land District—Coonamble; Shire—Gilgandra

No. 97966, Parish Eringanerin, County Gowen, 467.9 square metres at Gilgandra, being portion 124. DB80 H 1983.

APPENDIX B – OWNERSHIP REFERENCES (2)



Water over stone

Lambie Gorge is a site centred on Cooma Back Creek, a small stream, which in heavy rain can become what some specialists would call 'an active excavator' – or raging torrent. The Gorge owes its origins to a number of factors. The stream is superimposed on an ancient rock mass known as Cooma Granodiorite. This rock mass, or small 'pluton', covers 30 square kilometres.

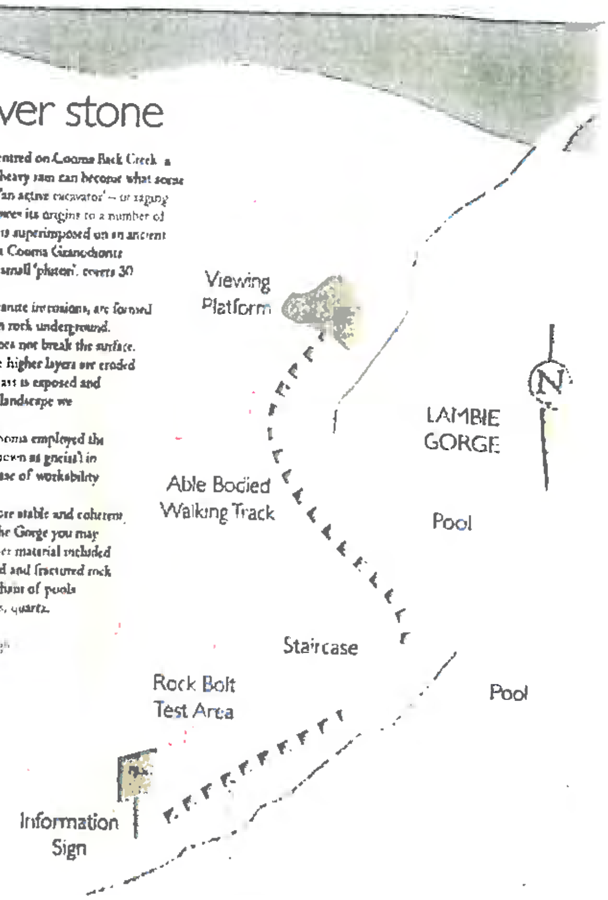
Plutons, or small granite intrusions, are formed by activity of molten rock underground. Initially the pluton does not break the surface, but over time, when the higher layers are eroded away, the underground mass is exposed and becomes the surface of the landscape we can see today.

Many of the buildings in early Cooma employed the more 'massive' form of this rock (known as gneiss) in their construction due to its relative ease of workability for stone masons.

Some of the rock takes the massive (or more stable and coherent) form; but in some plutonic rock found in the Gorge you may notice linear patterns with odd pieces of other material included. The Back Creek which cuts through the jointed and fractured rock has been able to cut out a narrow gorge, with a chain of pools which contains gravels from various sources: basalts, quartz, quartzites and other rock types.

Many of these same stone materials were used by Ngarigo people who were custodians of this 'Maneroo' landscape. Stone tools were made and used here on this land over two hundred years ago. Another site in the area has been dated as some 7,000 years ago.

References
Chappell B.W & White A.J.R: *Plutonic Rocks of the Lachlan Mobile Zone*
Whitten D.G.A & Brooks J.R.V: *The Penguin Dictionary of Geology*



'Rock Bolt'

An Australian Engineering Heritage Site

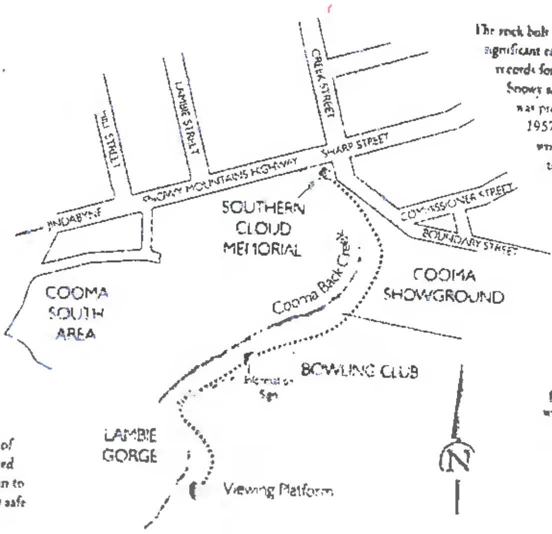
If archaeologists walked through the Lambie Gorge landscape they would immediately spot evidence of new as well as old tool-making technologies. Once upon a not-too-distant time Lambie Gorge was a kind of outdoor laboratory.

Fr   e mid 1950s the Snowy Mountains Hydro-Electric Authority designed tensioned steel rock bolts to form a permanent, underground support system. These were tested on the rock face at Lambie Gorge – and the success of the concept can be gauged in its adoption throughout the world on a wide range of significant engineering projects involving excavations underground.

What you see at the site

The testing site has fifty or so holes drilled [illegible] the rock-blasted vertical face where pullout tests were conducted. These were tests, basically, to establish the best way of anchoring the bolt in the hole.

The rock bolts are inserted in a designed pattern of drilled holes, immediately behind a newly excavated rock-face. They are tensioned, and then grouted in to form a reinforced rock arch – which results in a safe and permanent excavation.



The rock bolt technique proved to be a very significant contribution to the many world records for tunnelling achieved on the Snowy scheme. The rock bolt concept was presented in New York, in October 1957, at a gathering of leading world engineers. The success of this development generated enthusiasm and pride in the Snowy organization, feelings that became integral parts of its successful work.

The technique enabled very significant savings in construction costs - by the reduction in the material excavated, the elimination of steel sets to be used, reduction in the time for construction and greatly improved construction-worker safety.

Aboriginal stone cutting-tool as found at Lambie Gorge site

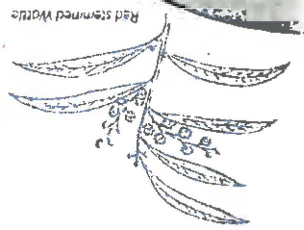
APPENDIX B – OWNERSHIP REFERENCES (3 - 2of2)

Flora

The vegetation in the Reserve is a woodland community of Black Cypress Pine and Ribbon Gum, a relatively rare combination. Although not highly regarded for their timber both trees can be utilised for fencing, fuel and some building construction. Other types of eucalypts can also be found in the area

Although Lambie Gorge is only a small reserve there is a surprisingly varied range of shrubs and smaller plants, including Red-stemmed wattle, Blackthorn, Shiny Cassinia and Woolly Grevillea whose flowers in early spring are popular with honeyeaters. In summer daisy bushes, native geranium and grasses make a colourful display.

Growing on a rocky outcrop is a patch of Elderberry Panax (*Polyscias sambucifolia*), a locally rare plant mainly confined to this Reserve. This is not the Elderberry of Europe from which wine and jam are made. Nevertheless the Aboriginal people do eat the ripe fruit of this Australian plant and make a medicinal drink from the squashed unripe berries.



Fauna

The woodland community around Cooma, of which Lambie Gorge forms a part, is home to over 30 species of birds, 5 frogs, the echidna and the platypus, 10 mammals, 4 snakes, grouped within 12 species of reptiles. One of these reptiles, the Long-necked Tortoise, chosen for the cover of this brochure, is of great significance to the Ngarigo people and to the Gorge. Of particular interest also is Rosenberg's Monitor, which can be observed waddling along during spells of warmer weather.

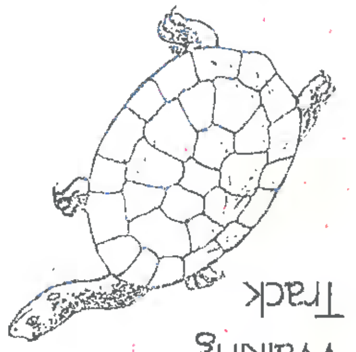
The largest dominant native fauna in Lambie Gorge is a community of Euros (Wallaroos), which have been observed in the area between the Nursing Home, the Gorge and the old stone wall.

No observations of small mammals have been made up to the present time, but in the past echidnas and platypuses have been seen in the Gorge area.

Many birds frequent the Gorge area: you may see hawks, parrots, kookaburras, crows, currawongs, finches and wrens. You might like to contribute to our knowledge of wildlife in Lambie Gorge by reporting your sightings to the Cooma Reconciliation Committee – you can phone your observations to:

John Gillard Ph. 6452-5221 or
Cooma Visitors' Centre Ph. 6450-1742

Lambie Gorge Walking Track



A Project of the Cooma Reconciliation Committee
&
The Monaro Ngarigo Lambie Gorge Restoration Committee

Financed by the NSW State Government Environmental Trust

European name

Following the first sighting of the extensive open grasslands of the Monaro – by Currie and Evans in 1823 – Cooma took its name from 'Kuma', the first grazing run. 'Coombah', a word in the Ngarigo people's language, has had two meanings ascribed to it: 'Big Lake' and "Open Country." The early surveyor, John Lambie, acquired part of the Kuma run. Lambie was later to be appointed District Commissioner for Crown lands in the Monaro Squatting District in 1837. In 1847 he also became the District Magistrate. He died in 1862 and was buried at Christ Church in Cooma. Named in his honour are the two streets, Commissioner and Lambie, which led to his home and office, situated on the present site of the Hion Centre car park. The Showground and Lambie Gorge were once known as 'Mr Lambie's Paddock'.

The steepness of the land in the Gorge has prevented development. Some land, however, was cleared in the late 1800s and a stone house built there with a small orchard and some pine trees. The Committee hopes to extend the walkway to the end of the Reserve at the 'Chinese Wall'. This is a dry stonewall that sits at the southern boundary at the upstream end of the Reserve. The wall was supposedly built by Chinese miners from the Kiandra goldfields.

During the 1980s a small reserve of Crown Land (1.042 ha) was declared. In 2003 the Cooma Aboriginal Reconciliation Committee received a NSW Government grant for the restoration of the local environment within the gorge and to enable the on-going protection of its varied and interesting heritage.

Ngarigo place

For all its European name the Ngarigo ancestors would have had an appropriate and meaningful name for their site and hopefully one day the Gorge will reclaim its original name. Many years prior to European settlement Aboriginal women used Lambie Gorge for many purposes. One such purpose was as a place of retreat. This was where women would go to talk to the Great Spirit in order to gain inner peace, strength and wisdom to help them in their day-to-day life.

Another purpose of the Gorge was for use as a Women's Camp. These Camps were used by women and male children (under the age of manhood) to learn from one another and to grow in knowledge. It was a place for women to share experiences and talk freely whilst making bonds of friendship. The women would have respected the land (Mother Earth) and the wildlife around them in the Gorge, taking only what was needed for their existence whilst there.

The conclusion that the Gorge is predominantly a women's site has been made by many experts and by talking to Ngarigo elders. Many of the stories given to us by the female elders have been passed on from generation to generation. Although no documented proof can be brought forward from those earlier days, artefacts and rock formations have verified the use of the site by Aboriginal women.

Today the Gorge, though altered in appearance as a landscape, has been passed on to the Ngarigo descendants and, at the same time, to the whole community as a place where individuals can view the local flora and fauna in their natural forms. The Gorge also remains a place where one can gain inner strength, harmony and wisdom – for those who seek them. The dedicated work, of all those of different ages and cultures, who have come along to working bees, to help rescue the site, together with the respect shown this site by present-day visitors will restore, in time, its natural and abundant beauty.

Visitors who are interested in the Aboriginal significance of the Gorge might like to read

Michael Young, Ellen and Debbie Mundy:
The Aboriginal People of the Monaro,
2nd edition, 2005

APPENDIX C – OVERALL MANAGEMENT PLAN

Plaquing & Interpretation of Lambie Gorge Rock Bolt Development Site Cooma, NSW
Management Plan #1 – March 2006

Table of Contents

1 Aim and Mission

Establish recognition as a unique Australian heritage site for the engineering development and mathematical basis of design for permanent hard-rock excavation support using rock bolts in tunnelling work. At the same time, provide a structure of management that facilitates and maintains the heritage site in perpetuity.

Give opportunity for the transfer of the heritage recognition to the outdoor travelling general public. The project strives to get a highly respectful appreciation, in educational terms, of a small, thoroughly researched component that revolutionised underground construction and safety. This appreciation is to be within the natural environment of the site. At the same time, the linkage to the Snowy Mountains Scheme's outstanding achievement, and the adoption of rock bolting in similar projects worldwide connects the unique site to indoor museums allowing for more detailed displays.

2 Management Plan

Foremost in the structure of a management plan for the rock bolt heritage site is to clearly define the separate responsibilities to be managed. It is vital that the initial effort of recognition through the heritage plaquing process, and making the site accessible to the public, does not later degenerate through the neglect of ongoing trusteeship planning.

There are other interested parties when the site is given heritage recognition, because these parties can have an ongoing benefit from it. So relationships will need to be established and maintained with the managers of the rock bolt site. Among the stakeholders there will be groups that may be regarded as having a particular historical connection to the site.

The management plan lays down a mechanism to seek government, corporate and private financing of the ongoing, but small, annual financial requirements. The greatest burden for funds is to provide for the initial conservation, and enhancement of the safety of the site. The costs of the ongoing maintenance and provision for the volunteers who are needed to give the educational guided tours to the public will need to be covered. The continuing availability of volunteer guides will need to be planned taking account of the changing demands from generation to generation. There is an obligation to inform and attract the passing parade to honour the rich engineering heritage on display at this site.

3 Conservation Plan

Central to the presentation of the Rock Bolt Heritage Site is the vertically split granite rock face in which about 50 bolt holes are drilled. Many of these holes have the anchored remains of the rock bolts projecting from them. There are several different types of bolts evident. Surrounding this focal point are the following significant features:

(a) In front of this face lies the remains of blasted away rock in which earlier anchoring experiments had been conducted.

(b) Vertical split holes some two metres behind the rock face in readiness for the preparation of a clean testing face for more anchor strength tests.

(c) Further 100m upstream on another natural rock face area fronting the gorge, are the remains of about 100 very early style anchored rock bolts projecting from their holes.

The climatic conditions that prevail in Cooma are at present unchanged from the time of the rock bolt experiments. This means that there is insignificant visible deterioration of the bolts themselves.

Whilst no damage would be expected normally, the element of wilful, destructive vandalism has been evident in recent times (spray paint and removal of descriptive signage). For this reason the conservation management will require wise and innovative measures from time to time, including barriers.

Weed control in the lush creek environment will be required to be applied sensitively to retain the ecology of the stream. At the same time, the verdant growth will require constant trimming in order to give confidence to visitors against the threat of snakes finding concealment adjacent to the access pathway.

The pathway and viewing area have only recently been prepared for safe walking access . This has been undertaken by voluntary work through the graces of Cooma Rotary and some engineering colleagues employed in Cooma who were very ready to donate their time. Flagstone steps were laid as well as surfacing the viewing area over a weed-mat underlay. This aspect of the Rock Bolt Heritage Site will require regular but minimal maintenance.

A number of technical papers, Snowy Mountains Authority memorandums, drawings, photographs and diagrams have already been assembled. In addition, unique machine-shop made components used in early anchoring experiments have been recovered from the original storage sheds. These sheds were associated with the engineering laboratories of Engineering Materials and

Engineering Geology of Scientific Services Division, Snowy Mountains Hydro-Electric Authority. The sheds are now the property of Snowy Mountains Engineering Corporation (SMEC) Australia. It behoves the project management team to determine, from time to time, how these archival components can be best used to enhance the limited amount that can be seen at the Rock Bolt Heritage Site. Indoor display areas of new and or existing museums are the ideal venues for such exhibitions. Thus the loose heritage items need to be curated and managed in order to preserve their original value and not have them lost from the collection.

4 Business Plan

In order to satisfy the requirements of the NSW Department of Lands, which is responsible for the land on which the Rock Bolt Heritage Site is situated, a set of local Trustees need to be appointed.

The lot of land in which the Rock Bolt Heritage Site falls, of approximately 1.042hectares, being Lot 3 of Deposited Plan 704165, was gazetted on 21 August 1984 by the NSW Parliament for environmental protection as a public place. This means that that the Department of Lands would welcome local trustees to act on their behalf in providing that environmental protection and preservation of the land. Then these trustees would be given the right to manage the space for the benefit of all the people.

The means to provide for the unique engineering heritage of the Rock Bolt Heritage Site, forming only a small portion of the total area of the Lot covering the right bank of Lambie Gorge proper, needs to be resolved by agreement with all parties concerned.

Like the whole of the land of Australia, Lambie Gorge does have evidence of the occupation by the Aboriginal People up until the time of European settlement in the 1830s. Whilst some of the Aboriginal People's descendants today behave with an extreme view of exclusive access over this Lot of land, the majority of today's Ngarigo Nation descendants, and the majority of their Elders, want to be able to take their share in their own heritage value of the place and share this with the heritage of others not of their race. The management of the Rock Bolt Heritage Site needs to be proactive in maintaining a social environment that promotes a true partnership with the Ngarigo Nation people as an expression of reconciliation.

Within the larger frame of trusteeship for the whole of the Lot of land, the Trustees for the Rock Bolt Heritage Site will need to act like Board of Governors. This means establishing governance policies for all aspects to allow public scrutiny at any time. Decision making, managing donated funds, organising volunteers, meeting all obligations, and providing open communications, are essential aspects of faithful business management.

5 Plaquing & Tourism Plan

The highest priority for the Overall Management Plan No 1 is to see the successful application for plaque nomination of the Rock Bolt Heritage Site as an item worthy of due recognition.

This recognition needs to proceed on several fronts simultaneously. Of most significance is the recognition by Engineers Australia through their Plaquing Sub-committee, and through them to Engineering Heritage Australia. Engineers Australia, established under Royal Charter in 1911, has the authority to independently assess the nomination for either a Historic Engineering Marker or a National Engineering Landmark.

The proposal to plaque has already been submitted by Mr W B Mills to the Plaquing Sub-committee. He has received a favourable reply to this proposal, with the encouragement to proceed to make the formal documented application. All the indications and research made since that time are that the Rock Bolt Heritage Site is of Australian national significance and to the engineering fraternity of the world.

Local Government and State Government heritage recognition will be guided principally by the assessment made by Engineering Heritage Australia. Nevertheless, the long duration of the process in each of these government jurisdictions needs to be consistently managed until the recognition is complete.

Already there is some interest by educational institutions which have picked up on the early publicity at the local level. A tourist brochure "Lambie Gorge Walking Track" features a condensed version of the great significance of the Rock Bolt Heritage Site. For the more technically minded, however, the Tourism Plan needs to be responsive to the additional needs. Appropriate volunteers to escort bus tour groups has the potential to raise revenue. Not only will the tour find the Rock Bolt Heritage Site of great interest and engage the mind, but the scenic beauty of the Lambie Gorge site will provide fresh-air relaxation from bussing while stretching the legs.

In the anticipation that the Rock Bolt Heritage Site will find full recognition as being of Australian national engineering significance, the management team will need to prepare for a an appropriate civic ceremony to mark the presentation of the heritage plaque. A lesser ceremony would be required should the less prestigious award be made, but it would not lessen the effort required to and carry through such a ceremony. What is being undertaken is to give due honour to those who pioneered the rock bolt technology that continues in practice today.

6 Update Plan For Overall Management Plan

The initial flush of enthusiasm to establish the Rock Bolt Heritage Site is needed to overcome years of local familiarity by the older generation. To engage the next generation to appreciate the significance of the first steps, once done, allows them to keep the subject alive by its own intellectual engagement with history.

Those who are Trustees and on the Board established under the Management Plan No 1 need to be able to pass their work into the hands of those willing to succeed them. Thus it is essential to plan formal procedures to allow such transitions.

The management plan itself will be required to undergo changes as times and demands on the heritage site change. Again, protocols need to be in place to allow a fully accountable process of introducing revisions to the management plan.

For those who have a vested interest in preserving the Rock Bolt Heritage Site, the Stakeholders, their invitation to participate in changes to be applied to the future management of the site needs to be underwritten. Only when there is a documented, stable and accountable process that will be adhered to, will the Stakeholders be prepared to make an ongoing commitment of support.

APPENDIX D – CLAIM TO UNIQUENESS: PUBLICATIONS (EXTRACTS)

1 American Society of Civil Engineers, Power Division Symposium on underground power stations, October 1957, New York, USA "Snowy Mountains Scheme T1 Power Station Rock Behaviour and Rock Bolt Support in Large Excavations" bt T.A. Lang, Associate commissioner Snowy Mountains Hydro-Electric Authority, Cooma, extract pp 16, 17, 23-35, 46, 47 & Refs.

2 Book "The Snowy Mountains Scheme" by Walter Diesendorf, 1961 Horwitz, extract pp52-58.

3 Book "Voices From the Snowy" by Margaret Unger, 1989 NSWUPress, extract pp 134-137 & refs.

APPENDIX D – CLAIM TO UNIQUENESS: PUBLICATIONS(EXTRACTS) (1)

AMERICAN SOCIETY OF CIVIL ENGINEERS, ETC., CONFERENCES & PAPERS

American Society of Civil Engineers, Power Division Symposium on underground power stations, October 1957, New York, USA "Snowy Mountains Scheme T1 Power Station Rock Behaviour and Rock Bolt Support in Large Excavations" bt T.A. Lang, Associate commissioner Snowy Mountains Hydro-Electric Authority, Cooma, extract pp 16, 17, 23-35, 46, 47 & Refs.

№ 111

SNOWY MOUNTAINS SCHEME — AUSTRALIA

T 1 POWER STATION

ROCK BEHAVIOR AND ROCK BOLT SUPPORT IN LARGE EXCAVATIONS

By
Thomas A. Lang
Associate Commissioner
Snowy Mountains Hydro-electric Authority
Australia

SYMPOSIUM ON UNDERGROUND POWER STATIONS
American Society of Civil Engineers
Power Division
October 1957 Convention
New York
U. S. A.

TABLE OF CONTENTS

Page

TABLES

APPENDICES

FIGURES

ROCK BEHAVIOUR AND ROCK BOLT SUPPORT IN LARGE EXCAVATIONS

T1 POWER STATION, SNOWY MOUNTAINS SCHEME, AUSTRALIA

8763

Thomas A. Lang,[1] A.M. ASCE

SYNOPSIS

The excavation in granitic type rock for the large T1 Power Station was stabilised by using rock bolts.

The effects of jointing in the rock and excavation sequence on stress distribution around the Station were studied with photo-elastic models.

The use of rock bolts to create a structural entity from jointed and fractured rock was investigated with photo-elastic models and small and large scale tests using uncoherent crushed rock material.

Tests were made of the behaviour in hard rock of slot and wedge type bolt anchorages to determine the relative dimensions of anchorage assembly and drill hole, and the installation technique necessary for satisfactory performance.

The excavation operations in the Power Station are described and related to the movements and behaviour of the rock, roof ribs, and abutments. This behaviour is consistent with the rock bolts creating a diaphragm around the excavation which, in effect, is behaving as an integral elastic shell.

NOTATION

The letter symbols adopted for use in this paper are defined where they first appear in the illustrations or text, and are listed in Appendix 1.

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1. Associate Commissioner, Snowy Mountains Hydro-electric Authority, Cooma, New South Wales, Australia.

completely non-elastic and either exhibit all the properties of a plastic or viscous material. The joint system may range from joints at wide intervals of many feet to closely spaced joints of a few inches. Although diamond drilling and exploratory tunnels give much valuable information the detailed condition of the rock is not known until the excavation is made. The materials which may be encountered can range from almost intact rock to a material that resembles crushed rock aggregate. In the latter case although the size of the fragments may be comparable to aggregate sizes, they never have the random arrangement found in aggregate.

In the literature relating to underground excavations, and particularly in regard to jointing and joint patterns, the term "arch action" is often used with an air of mystery that leads to confusion and even misrepresentation. An excavation or structure that has an "arch shape" is often regarded as being inherently strong and economical because of "arch action". Used in this way the term is, in many cases, only a cover up for lack of knowledge regarding the conditions actually existing in the rock or structure. An arch differs from a beam in that it has horizontal as well as vertical forces acting on its ends. If the abutments yield so that the horizontal forces are relieved the arch becomes a beam. If the term "arch" is used to describe the geometrical or architectural form it is better to refrain from talking of arch action.

Much has been written and could be written about jointing, its occurrence, pattern, and causes. However, the fact is that rock is jointed and must be dealt with as such if a satisfactory structure is to be built.

Rock Bolts.

During the last decade, rock bolts have come more and more into prominence as a means of supporting rock excavations. Prior to the World War II they had been used only to a limited extent. The view that rock bolts only "pin" or "nail" blocks or slabs of rock which are loose to the sounder rock behind them, is erroneous. Rock bolts are useful for this

purpose and have been so used for a long time but ad hoc use of rock bolts for this purpose without understanding can be dangerous.

The term rock-bolting, as used here, means the designed use of rock bolts to develop jointed rock into a structural entity which can competently play its part in a structure such as a power station.

Another concept in regard to the behaviour of rock bolts, is that they create a principal compressive stress normal to the free surface of an excavation where, without them, there would be only one principal stress parallel to the surface. This is borne out by their very effective use to stabilise "popping" rock. This implies that, either at or immediately behind the free surface, the bolts form a diaphragm of material somewhat less in thickness than the length of the rock bolt, which can be used as a structural member whose properties can be ascertained and whose behaviour can be assessed and designed for. It is obvious that, if rock bolts are to be designed to carry out the tasks enunciated above, then it is necessary to know their behaviour in relation to both intact and jointed rock. This requires not only knowledge of the behaviour of rock bolts but also of the behaviour of jointed rock, either with or without rock bolts. Before describing some of the investigations which have been carried out and the procedures which have been developed, consideration will be given to a few simple joint studies which illustrate rock joint behaviour and the effects which rock bolts might have on it.

Simple Joints and Rock Bolts.

For underground excavations the rock is generally confined within the rock mass except at the free face. The case of loose surface blocks or slabs of rock offers no particular problems.

For rock at the surface of an excavation there is in general one principal stress acting viz., the stress parallel to the free surface, and the simple joint studies are confined to two dimensional cases of this kind (Figs. 12 and 13). To simplify the presentation resultant forces on a block have been used, viz. P represents the resultant of the forces on the joint parallel

ROCK BOLT PHOTOELASTIC INVESTIGATIONS

A guide to the behaviour of rock bolts and the stress condition they cause was obtained by photoelastic investigations. These covered such variables as tension in bolt, length of bolt, spacing between bolts, angle of bolts to free surface and the effect of bolts at re-entrant angles and other construction features. Examples from the series of tests with bolts normal to the free surface are given in Fig. 18. The models were CR.39 plastic 1/4 in. thick and of various widths and lengths to suit the matters being investigated. Bolts were simulated by loading heads connected by steel piano wire on either side of the plastic plate. Analyses of the stress patterns show very clearly that to develop a zone of uniform compression between the ends of the bolts l/s should be not less than 2. At this value the zone is relatively narrow whereas for l/s = 3, it is approximately two-thirds of the bolt length (Fig. 18). Between the bolts, tension develops in the surface and there is a small area subject to tension which reaches its maximum mid-way between two bolts.

Similar investigations were carried out for bolts at 45° to the free surface with bolts in one direction and also crossed. In all cases, it was found that the l/s ratio had to be approximately 2 or more to give a zone of uniform compression. Fig. 18 shows stress patterns for an unconfined condition, i.e., no end restraint. Under this condition, uniform tension is induced in the material at right angles to the direction of the bolt. If end restraint or end loading is applied, then the tension is eliminated by a developed compression. Following the simple joint studies a model (Fig. 19) was constructed to confirm that material with regular joints could be stabilised by rock bolting. The regular joint pattern selected approximated the pattern encountered in the machine hall roof. The model consists of approximately 640 pieces of CR39, 1/4 in. thick. Each block has smooth sides and stability is dependent entirely on the compression developed in the mass by the three rock bolts. End loading was not imposed but was developed against

and restraint by tensioning the rock bolts. The model was free standing and the patterns shown in Fig. 19 were obtained with circularly polarised monochromatic light. It can be seen that stress concentrations are occurring at the corners of most of the small blocks, i.e., the blocks are sliding and rotating. The transfer of stress from bolt to bolt can also be seen together with comparatively large areas of fairly uniform stress. The conditions in this model were far worse than would be encountered in actual construction. These photoelastic studies of bolt behaviour are being continued to cover many of the situations met with in construction practice.

Another conclusion from the photoelastic investigations was that pattern bolting would be far more efficacious in controlling the unknown conditions behind the surface of an excavation than random spotting of individual bolts. Pattern bolting has been followed throughout the T1 Power Station excavation and the ratio l/s has been between 2 and 3 for this work. No jointing pattern in the rock is completely regular and the casual spacing of bolts based on superficial surface conditions could well lead to disastrous consequences.

ROCK BOLT TESTS - CRUSHED ROCK.

It was mentioned earlier that rock met with in practice varies from intact material to highly crushed and fractured rock. The photoelastic studies gave an insight into rock bolt behaviour in an elastic, isotropic material. Therefore, investigations were made into the behaviour of bolts when used to stabilise an uncoherent crushed rock mass.

Box and Bucket Models.

These models were qualitative and are illustrated in Fig. 20. The first consisted simply of a rectangular box with a perspex front which was filled with small crushed rock 3/16 in. in size using model rock bolts. The mass was compacted by vibration to eliminate some of the looseness inherent in this material. After tightening the bolts the box was inverted and it was found that this material could be satisfactorily supported, ((a) & (b) Fig.20). The second qualitative test was made with an ordinary household bucket ((c) and (d) Fig. 20). The lateral pressure developed by the bolts was sufficient to support not only

the weight of the material in the bucket but an external load as well. It was concluded that the material was behaving in a quasi-plastic manner under the pressure created by the rock bolts, thus developing the lateral forces.

Machine Hall Roof Model.

A model of the machine hall roof using this material was also constructed (Fig. 21). The model had provision for side and top loading of the crushed rock material. After several trials, it was found that the material could be successfully bolted and could not be failed even although some hundreds of pounds was added as a top load.

Tension Zone.

In the photoelastic investigations it was noted that at the free surface between rock bolts there existed a small tension zone. In the uncoherent crushed rock material there was a fall-out of loose material in this zone. Such fall-out occurred and can be seen in (b) and (d) Fig. 20 where small vaults have been created between the boundaries of the rock bolt washers. This was the first lead to an explanation as to why in practice relatively light steel wire mesh support between bolts was capable of stabilising loose rock surfaces. The fall-out of this small amount of loose material in the tension zone between bolts could easily start an "unravelling" of the whole mass due to the movement of certain key fragments which, although carrying little or no loads, may start a run if they are removed. This action was demonstrated with the machine hall roof model and examined by means of high speed moving pictures.

In the machine hall roof model the very small amount of support needed to cope with these tension zones was demonstrated by using one cigarette paper under each rock bolt washer, (Fig. 21). Following the completion of bolting the cigarette papers were burnt away and the whole mass still remained stable. However, all work on the small models has been carried out without support between bolts. This could lead to a greater proportion of failures but it was done deliberately to examine the nature of the fall-out, the shape and extent of the vaults created, and the mechanism of failure.

Single Bolt Tests.

Following this preliminary work, investigations were begun using single bolts in cylindrical tubes. This gave an opportunity to have experimental results in a form that could be analysed more easily. These tests have shown that when the bolted material is just stable there is a relationship between the clear space s between bolt washers, the mean particle size m, the bolt length l and the bolt tension B. Although generalised forms of the relationship have not yet been fully resolved the ratio

$$F = \frac{s}{m} \tag{12}$$

has proved to be a useful parameter. For example, in investigating the effect of particle shape, a series of tests were made using marbles in a vertical box having a width slightly greater than the marble diameter and fitted with an adjustable opening in the bottom. For an F number of 3 the marbles were always stable. If the F number was 4 they invariably failed.

Rod Model.

Following the results of the experiments with the marbles the model shown in Fig. 22 was constructed. It consisted of 3 in. x 1/4 in. cylindrical rods of polystyrene made up into the form of a beam. It was constructed in the belief that the circular shape was probably the least stable which could be used. The F number adopted was 3 and the bolts were spring loaded so that bolt tension could be determined. The loading jig enabled end loads to be applied or measured and also provided for free or fixed end conditions. The fall-out between bolt washers, thus creating vaults, can be easily seen. The beam was loaded with a concentrated load ((b) Fig. 22) and was found to behave approximately elastically up to failure, which, where it occurred, was sudden and catastrophic. For an F value of 4 the beam was always unstable.

Rock Bolt Tests - Crushed Rock.

Following the small-scale tests larger scale tests for material similar to that which might be encountered in excavation practice and using

bolts of large size were begun and are continuing. The testing apparatus consists of a box 4 ft. x 4 ft. x 4 ft. (Fig. 23) with vibrating wire pressure cells mounted in the sides to measure lateral pressures, and a hydraulic jack assembly to apply and measure central loads.

From the small scale tests it was concluded that bolting of the crushed rock was creating from the uncoherent fragmented rock mass a quasi-elastic diaphragm between the ends of the bolts. Therefore, in the larger scale tests it was decided to construct diaphragms with various thicknesses. The method of using the testing rig shown in Fig. 23 is to bolt a temporary floor of planks underneath the box, place the rock bolts in position, fill the box to the required depth, assemble and tension the bolts, and then remove the floor. Following this the diaphragm was loaded, and deflections, loads, lateral pressures and bolt tensions measured.

The results of several of these tests are shown in Figs. 24, 25, and 26, and in Table 2. (a) Fig. 24 shows the bolting of crushed rock material 3 to 5 in. in size with bolt tensions of 7,500 lb. per bolt. After initial failures with larger values an F number of 3.25 was selected and the rock mass was successfully supported. It supported a central load of 13,000 lb. which was the maximum which could be applied with the loading jack. It was noted that the bolt tension became less as the load was cycled and finally failure was induced by deliberately reducing the bolt tension to zero.

(b) Fig. 24 was a test with smaller material, 1.5 to 2.25 in. in size with an F number of 4.25, and a bolt length of 23 in. Results of this test are given by curve 1, Fig. 26. After removal of the bottom the loose rock in the tension zone between the washers fell out, creating the vaults seen in (b) Fig. 24. Load was applied and although there had been no indications of failure, a few fragments dropped out at 7,000 lb., D (Fig. 26) and commenced an unravelling leading to failure. In order to prevent this and to demonstrate how flimsy a support may be needed between the bolts, the test was repeated with 2 in. by 24 gauge chicken wire netting placed beneath the bolt washers, ((a) Fig. 25), but was not attached to the sides of the box. There was little

bulging of the wire and the model was loaded and unloaded in accordance with the sequence shown graphically in Fig. 26. Cyclic loading was applied at points 2, 3, 5, 7, and 9, (Fig. 26). Small permanent deflections occurred with each cyclic loading in the early stages, e.g. between 3 and 4 (Fig. 26), and at each cycling point the loading and unloading was continued until the additional permanent set per cycle had fallen to 0.001 in. At 5, 7, 9, it will be observed that, after a number of cycles, further permanent deflection ceased and constant hysteresis loops were obtained. At 8, the load was left on overnight and there was a relaxation of strain and load in the 12 hours. After bringing it back to the maximum load, viz. 13,000 lb., the load was reduced to zero and a series of cycles at 0 to 10,000 lb. applied. At this stage, 10, Fig. 26, the chicken-wire was cut away, ((b) Fig. 25) when fall-out in the tension zones occurred with typical vaults appearing between the bolts. It was again loaded from 10 to 11 during which rock fragments were falling out, and left standing at 13,000 lb. for an hour. Occasional fragments fell, giving a small relaxation in strain and load. The mass was then saturated with water and it failed by general collapse.

Significant features illustrated in Table 2 and Fig. 26 are

(a) the general curve of the envelope 2, 3, 4, 6, 8, 11 is typical of a brittle material,

(b) the unloading and reloading curves for the cyclic loading follow a power law of the form $W = b\,(h-a)^n$ and show elastic hysteresis,

(c) the crushed rock material behaves quasi-plastically and after working has a "yield" point which increases in a manner analagous to "strain hardening" for ductile metals.

The other test results given in Table 2 are for crushed rock identical with that used for tests in Fig. 26, with 4 bolts instead of 9. However, the bolt tensions were increased from 5,000 lb. to 15,000 lb, following results from the small scale tests which showed that if bolt tensions were increased, then F numbers could be increased also. 2 in. by 24 gauge chicken-wire was

used under the bolt washers. It was anticipated that the wire in this case would be carrying a larger load than in the earlier test and this proved to be the case. Loading was carried through a series of Cycles and the material was quite stable up to the maximum load of 13,000 lb. Again, the chicken-wire was cut but this time the model failed by unravelling when about three-quarters of the chicken-wire had been removed.

These investigations demonstrate -

(a) that crushed rock can be stabilised by rock bolts and the diaphragms formed between the ends of the bolts behave as an integral, quasi-plastic structural member,

(b) that loading and unloading causes "working" of the fragments with reduction in tension in the bolts thus demonstrating the need for re-tightening bolts after vibration or other working,

(c) the very flimsy nature of the support that is needed to cope with loose material in the tension zone vault between the bolt washers,

(d) the importance of supporting such loose material so as to prevent unravelling of the whole fractured mass behind the bolts when under load.

Bolts have been used in such locations at several points in the T1 Power Station work. Generally speaking, steel mesh lagging was not needed in the T1 Power Station except over the upstream wall where it was placed to prevent danger to workmen from small loose rock fragments rather than for structural reasons.

Analyses of the conditions pertaining in the bolted crushed rock diaphragm have not reached the stage where a tried and working formula can be put forward.

ROCK BOLT INSTALLATION

At the time these works began, much information had been published about slot and wedge type bolts in sedimentary rocks, but very little information was available on the use of these bolts in hard rock. The opinion

seemed to be held, almost universally, that the slot and wedge type anchorage was quite satisfactory in the softer rocks, but was not satisfactory in hard rocks such as granite. Therefore tests were carried out to ascertain the competency of bolts in granite and to determine a satisfactory technique for installation. The testing program centred around the slot and wedge type anchorage, and 200 bolts of this type were tested. Some 60 bolts with expansion type anchorages were tested for comparison purposes.

Rock Bolts used in T1.

The rock bolts used in T1 consist of a mild steel bar, 1 in. nominal diameter, with 6 in. of rolled thread (1 in. Whitworth) at one end and, at the other end, a flame-cut diametrical slot, in which the flame-cut wedge was inserted. A dimensioned sketch of this anchorage is given in (a) Fig. 27. The diameters of the drill holes were maintained between 1-1/4 in. and 1-3/8 in. and lengths were 10 ft. 15 ft. and 20 ft. with occasional odd sizes for special work.

The ultimate strength of the bolts was approximately 40,000 lbs. (60,000 psi) and the yield point was 22-24,000 lbs. (33-36,000 psi).

Strength of Rock Bolts.

The so-called "strength" of a rock bolt is determined by its anchorage and a bolt is considered to have failed if it is impossible to hold the required tension in the bolt owing to continuing slip of the anchorage. In practice, tension in the bolt would normally not be greater than the yield point of the steel and therefore the breaking of the steel shank does not arise. In the tests a number of bolts were taken well over the yield point of the steel and bolts were broken either in the thread or in the prongs in the vicinity of the wedge. The load in the bolt at which the anchorage slips depends on the driving technique, the relative magnitudes of hole diameter, bolt diameter, slot width, and wedge dimensions.

The relative dimensions of the anchorage and the installation technique are satisfactory and the bolt can be considered competent if the tension in the bolt can be raised to the yield point of the steel or other

required "proof" load without significant anchorage slip.

Test Procedure.

The test procedure consisted of drilling the hole, inserting and driving the bolt, pulling the bolt with a hydraulic jack assembly and measuring bolt tension, anchorage movement, and bolt elongation. The tests were all carried out with 1 in. nominal diameter bolts and included drill hole diameters from 1-1/16 to 1-5/8 in. wedge sizes from 1/2 to 1 in. and bolt lengths from 2 to 20 ft. Driving time, air pressure, length of bolt, and the number of impacts per minute by the driving hammer, were also varied and the effect on anchorage competency noted. It was found that no trouble was experienced in obtaining a satisfactory anchorage if the air pressure at the driving hammer was not less than 75 psi, (preferably 85-100 psi) the driving time was 20-30 seconds, and the hammer gave between 2-3,000 impacts per minute.

Variation in anchorage efficiency was observed between holes which were drilled vertically downwards, horizontally, and vertically upwards. The vertical-up holes were self-cleansing, and after cleaning drilling sludge from horizontal and vertical-down holes, it was found that these holes gave results equal to the vertical-up holes.

Although it may be reasonable to assume that the longer bolts would absorb more energy and therefore the anchorage would not be driven as satisfactorily as it would with shorter bolts, the test results, covering bolt lengths from 2 to 20 ft. were not decisive in this regard. However, work in the power station did show that more care and attention were required in driving the 20 ft. bolts than the shorter bolts if satisfactory anchorages were to be obtained.

The various dimensions used in the anchorage assembly were correlated by

$$\epsilon_B = \frac{w + d - t - D}{D} \qquad (13)$$

in which D is diameter of drill hole, d is diameter of bolt, t is width of

slot, w is wedge thickness, and ϵ_B is the diametral strain of the anchorage assembly assuming the assembly is deformed to the hole diameter.

The test results in terms of ϵ_B and two "proof" loads are summarized in Table 4. This shows that, provided ϵ_B is 0.15 or greater, there should be no difficulty in achieving a 95 per cent. satisfactory performance for bolt loads up to 20,000 lbs. and 80 per cent. for bolt loads up to 30,000 lbs. If ϵ_B is less than 0.15 then only 65 per cent. to 46 per cent. of the bolts are satisfactory.

Anchorage Behaviour

When the wedge is inserted in the slot and the wedge and bolt driven home against the end of the drill hole, the prongs of the bolt spread, touch the sides of the drill hole at A, (a) (Fig. 27), and from A to B are either plastically deformed by the rock or plough a groove into the rock or both. If the prongs of the bolt do not plough a groove in the rock and the wedge is driven home, then ϵ_B the diametral strain of the anchorage assembly is given by Equation (13).

A number of anchorages, after driving and loading, were removed from the rock and examined. The contact areas were generally of the types shown in (b) and (c) Fig. 27. Type (b) occurred where the wedge may not have been driven quite home, whereas (c) occurred if the wedge had been driven fully home or even slightly past the end of the bolt. A typical contact area is shown in (d).

In the course of the tests it was found that, on initially tightening the bolt after driving, anchorage movements took place. As the loads increased further movements sometimes took place. When the anchorage did not slip without further increase in load, the load could be removed and again applied to its previous value before further slip took place. In other words, the anchorage itself had a "yield" point and behaved as though the junction between the steel and the rock had the property of "strain hardening".

It was also observed that in the center of the contact area rock fragments and minerals were adhering to steel as at A in (b), (c), and (d),

Fig. 27. Closer examination, ((e) Fig. 27), revealed that in this central area, the steel had been severely deformed plastically and showed characteristic shear slip surfaces, A, and that the minerals adhering to it, B, also showed shear slip surfaces. These minerals appeared to have also been pulverised and compressed under very high pressure. That the steel in this area had undergone very severe plastic deformation was confirmed by a hardness survey of the contact area. The unworked bolt shank had a Brinell hardness number of 150 compared to 160 just inside the edge of the contact area and a maximum of 250 in the center of the contact areas. The contact areas were measured and it was found that the semi-elliptical type of contact area ((b) Fig. 27) was of the order of 0.8 sq. in. in area and the "streamlined" form ((c) Fig. 27) had an area of about 1 sq. in. Then if B is the load in the bolt, P is the load on each contact area, and μ is the coefficient of friction between the steel and the rock.

$$B = 2\mu P \tag{14}$$

The ordinary coefficient of friction of steel on rock is about 0.5 and if this value be taken, the above equation makes P equal to B. As the contact areas average approximately a square inch, the mean pressure over the contact area would be 20,000 psi and 30,000 psi for the "proof" loads given in Table 4.

If it is assumed that the distribution of stress over the semi-ellipse approximates to a quadrant of an ellipsoid and over the "streamlined" form to one half of the comparable solid of revolution, then the maximum stress σ_m in the case of the semi-ellipse would be given by the equation,

$$B = 0{\cdot}25\, \sigma_m \tag{15}$$

and in the case of the "streamlined" form

$$B = 0{\cdot}33\, \sigma_m \tag{16}$$

If B is 30,000 lb. then σ_m would be 120,000 psi in the first case and 90,000 psi in the second case.

Severe plastic deformation as found at A and B, ((e) Fig. 27) begins at a pressure equivalent to about 0.4 of the Brinell hardness number (9), (10). With a Brinell value of 150 kgm per sq. mm. (214,000 psi) the pressure for plastic deformation would then be about 85,000 psi which is consistent with the values for σ_m given above.

At the centre of the contact areas both the steel and the rock are under a condition of high triaxial compression and are entering the range where it might be expected that the rock minerals would also be deforming plastically (7), (8). Under these conditions there is probably strong adhesion between the steel and the rock as well as a very intimate and strong mechanical bond at the junction.

These features of the steel-rock junction are consistent with the stick-slip motion of the anchorage under increasing load which was noted during the tests.

The deformation of the anchorage is elastic as well as plastic and if the anchorage "sticks" at any applied load then this load must be exceeded before it "slips", i.e., the "stick-slip" load increases as the elastic yield point of the steel is increased by strain hardening. The elastic lateral deformation of the anchorage assembly under increasing bolt tension in accordance with Poisson's ratio will also contribute to the "stick-slip" nature of the anchorage movement.

In hard rock, bolts with a slot and wedge anchorage can be installed satisfactorily and, if so desired, can be given an initial "proof" load to ensure a margin over the working load.

Torque - Tension.

The most convenient method of obtaining a required tension in a bolt is to use a torque-controlled impact wrench.

Tests were made to determine the torque-tension relationship for the

bolts used in T1. The tests gave a torque-tension relationship in accordance with the equation

$$T = kBd \tag{17}$$

Where T is the torque applied to the bolt nut in pounds-feet, k is a constant, B is tension in the bolt in pounds, and d is bolt diameter in inches. The average value for k was 0.0166.

Field conditions, particularly angle between the bolt axis and the plane of the bearing plate, can cause large deviations from Equation (17) and care is needed to ensure that required bolt tensions are obtained.

CONCLUSION

The use of rock bolts as the major support in the excavation of the machine and transformer halls of the T1 Power Station has been successful and has been the means of preventing any major falls of rock either in the excavation and construction of the roof or in the excavation of the machine hall. The strain meter readings indicating high loads in a number of the roof ribs, which are confirmed by the cracking and spalling of the concrete in Ribs Nos. 11 - 15 on the downstream side of the machine hall, and the clinometer readings would normally lead one to expect fracture and cracking of the rock and opening up of joints in the walls of the machine hall excavation, particularly just below abutment level, where maximum movement and rotation has taken place. That such symptoms have not appeared is due to the rock bolting, the general pattern of which is shown in Fig. 36. The bolts are from 10 ft. to 15 ft. long and have created a diaphragm (some 7 - 10 ft. thick) around the whole excavation which in effect is behaving as an integral elastic shell. This is consistent with the action and behaviour of rock bolts as demonstrated by the investigations which have been carried out, and also demonstrates the efficacy of slot and wedge type anchorages in hard igneous rocks. It is proposed to use rock bolts as the primary support in future underground power stations and tunnels and investigations into their use and behaviour are continuing.

The investigations into the bolting of crushed rock material have demonstrated that it is feasible and practicable to reconstitute highly fractured and closely jointed rock with rock bolts and relatively light steel mesh. This was demonstrated at several minor locations in the T1 Power Station work by the difficulty encountered in removing rock in construction drives which had been "temporarily" bolted.

Estimates of the quantity of conventional steel rib support that would have been required for the machine hall roof as against the rock bolt

support show that eight times the weight of steel would have been required and the cost would have been five times greater.

ACKNOWLEDGEMENT

The success of the excavation and construction methods followed for the T1 Power Station has been due to the integrated efforts of a large group of the Authority's engineering and technical staff engaged in laboratory research, field investigations, design, and construction. The willing co-operation of the joint venture Contractors - Compagnie Industrielle de Travaux, Entreprise Fougerolle pour Travaux Publics, Societé Nationale de Travaux Publics, Etudes et Entreprises, L'Entreprise Industrielle, Societé General D'Entreprises - in working out, with the Authority's staff, field procedures and new techniques, has also contributed very greatly towards the successful construction of these large excavations.

TABLE 1

AVERAGE ROCK PROPERTIES

ITEM	TYPE 1 GRANITE		TYPE 2 GRANITE		
	Exploratory Tunnel	Machine Hall	Exploratory Tunnel	Machine Hall	Transformer Hall
Specific Gravity (Bulk)	2.73	2.71	2.70	2.73	2.71
Porosity (% Volume)	0.30	0.70	0.30	0.30	0.50
Compression					
Ultimate Compressive Strength (1000 psi)	19.5	21.0	21.0	19.5	14.3
Limit of Proportionality (1000 psi)	13.2	12.9	12.5	12.5	11.6
E (10^6 psi)	10.3	8.4	10.2	9.4	7.3
Poisson's Ratio ν	-	0.22	0.25	0.25	0.23
Angle of Fracture	65°	67°	70°	73°	70°
Tension					
Ult. Tensile Strength (1000 psi)	1.18	1.11	0.93	1.10	0.99
Limit of Proportionality (1000 psi)	0.88	0.58	0.83	0.56	0.40
E (10^6psi)	7.6	6.5	9.3	7.3	6.7
Angle of Fracture	5°-10°	5°-10°	5°-10°	5°-10°	5°-10°

ITEM	TRANSFORMER HALL TYPE 2 GRANITE			MACHINE HALL TYPE 2 GRANITE		
Triaxial Tests						
Confining Pressure 1000 psi	0	5	15	0	5	15
Axial Ult. Compressive Strength 1000 psi	14.3	35.3	60.2	19.5	49.9	80.3
Angle of Fracture	65°	60°	65°	65°	65°	60°

TABLE 2.

ROCK BOLT TESTS - CRUSHED ROCK.

Test	ROCK SIZE Range ins.	ROCK SIZE Mean ins.	Bolt Length l in	SPACING Bolts s_1 ins.	SPACING Clear s_2 ins.	Washer Size ins.	SELECTED $F = \frac{s_2}{m}$	RESULTS Bolt Tension B 1,000 lb.	Lateral Pressure p lbs./ sq.ft.	Load W 1,000 lbs.	Deflection h ins.	Remarks
1 4 Bolts	3-5	4	46.	23	13	10x10	3.25	7.50	821	-	-	
								2.00	998	13.0	1.600	Failed by reducing
								1.35	990	10.0	1.908	B to zero
2 9 Bolts	1.5-2.25	1.875	23	16	8	8x8	4.27	5.00	1750	-	-	2 in. x 24g Wire netting support
								5.00	2835	13.0	0.546	
								4.85	2350	0.0	0.415	Wire netting removed
								4.85	2575	13.0	0.619	Failed after saturation
3 4 Bolts	1.5-2.25	1.875	39	16	13	10x10	6.93	15.00	1520	-	-	2 in x 24g Wire netting support
								10.40	2440	13.0	0.825	After 35 additional cycles
								10.40	2140	13.0	0.983	Failed on removing wire support.

Average Weight of Crushed Rock = 105 lbs. / cubic foot

TABLE 3

ROCK BOLTING STATISTICS

Feature	Number of Bolts Plain No.	Grouted No.	Total No.	Total Length 1,000 ft.	Area Supported 1,000 sq.ft.	Area per Bolt for Pattern Bolting sq. ft.	Length of Bolts Used
Machine Hall							
a. Roof	2,194	-	2,194	26.7	25.4	11.6	) 10', 15', 20'
b. Walls	261	861	1,122	16.5	30.0	27.0	) Few 7' and) 12'
Transformer Hall							
a. Roof	1,366	-	1,366	17.0	10.0	6.6	)
b. Wall	40	83	123	1.4	6.0	44.0	) 10' and 15')
Tailrace Portal - Open Cut	62	177	239	2.4	15.0	63.0	10'
Totals	3,923	1,121	5,044	64.0	86.4	17.1	
Tunnels and Shafts	940	-	940	Not pattern bolting			8' and 10'
TOTAL	4,863	1,121	5,984	-	-	-	

TABLE 4

SLOT AND WEDGE ANCHORAGE TESTS

1 in. Dia. M.S. Rock Bolts

ϵ_B	< 0.15		0.15-0.25		0.25-0.35		> 0.35	
	Proof Load - 20,000 lbs.							
	No.	%	No.	%	No.	%	No.	%
Total Bolts Tested	31	100	98	100	68	100	18	100
Competent	20	65	93	95	66	97	18	100
Failed	11	35	5	5	2	3	0	0
	Proof Load - 30,000 lbs.							
	No.	%	No.	%	No.	%	No.	%
Total Bolts Tested	22	100	38	100	20	100	4	100
Competent	10	46	31	82	17	85	4	100
Failed	12	54	7	18	3	15	0	0

APPENDIX I

NOTATION

$\sigma_x, \sigma_y, \sigma_z$	Normal stress on planes perpendicular to x, y, and z axes.
σ_m	Maximum stress.
X, Y, Z	Body forces.
ρ	Weight per cu. ft. of rock.
g	Acceleration due to gravity.
ν	Poisson's Ratio.
N	Ratio of horizontal to vertical stress in gravity field.
σ_V	Vertical stress in a gravity stress field.
σ_H	Horizontal stress in a gravity stress field.
P	Resultant force.
W	Weight of a discrete block of rock or a concentrated load.
B	Tension in a rock bolt.
α	Angle between surface of joint and normal to the free surface.
μ	Coefficient of surface friction.
ϕ	Angle of friction defined by $\tan \phi = \mu$
M	Moment
V	Shearing force.

c	One half of depth of block in which a joint is subject to moment M.
F_n	Fringe value for normal stress.
F_s	Fringe value for shear stress.
l	Length of rock bolt.
s, s_1	Spacing of rock bolts.
s_2	Clear space between rock bolt washers.
m	Mean particle size.
F	Ratio of s_2 to m.
h	Displacement or deflection.
D	Diameter of hole drilled for rock bolt.
d	Diameter of rock bolt.
t	Width of slot in rock bolt.
w	Wedge thickness.
$\leftarrow$ $\curvearrowleft$	Direction.
ϵ_B	Diametral strain of anchorage assembly for slot and wedge type bolt.
T	Torque.
k	Constant in torque - tension equation.

APPENDIX II

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(8) "Theory of Flow and Fracture of Solids" by A. Nadai, Vol. 1. McGraw Hill Book Co. Inc., 1950.

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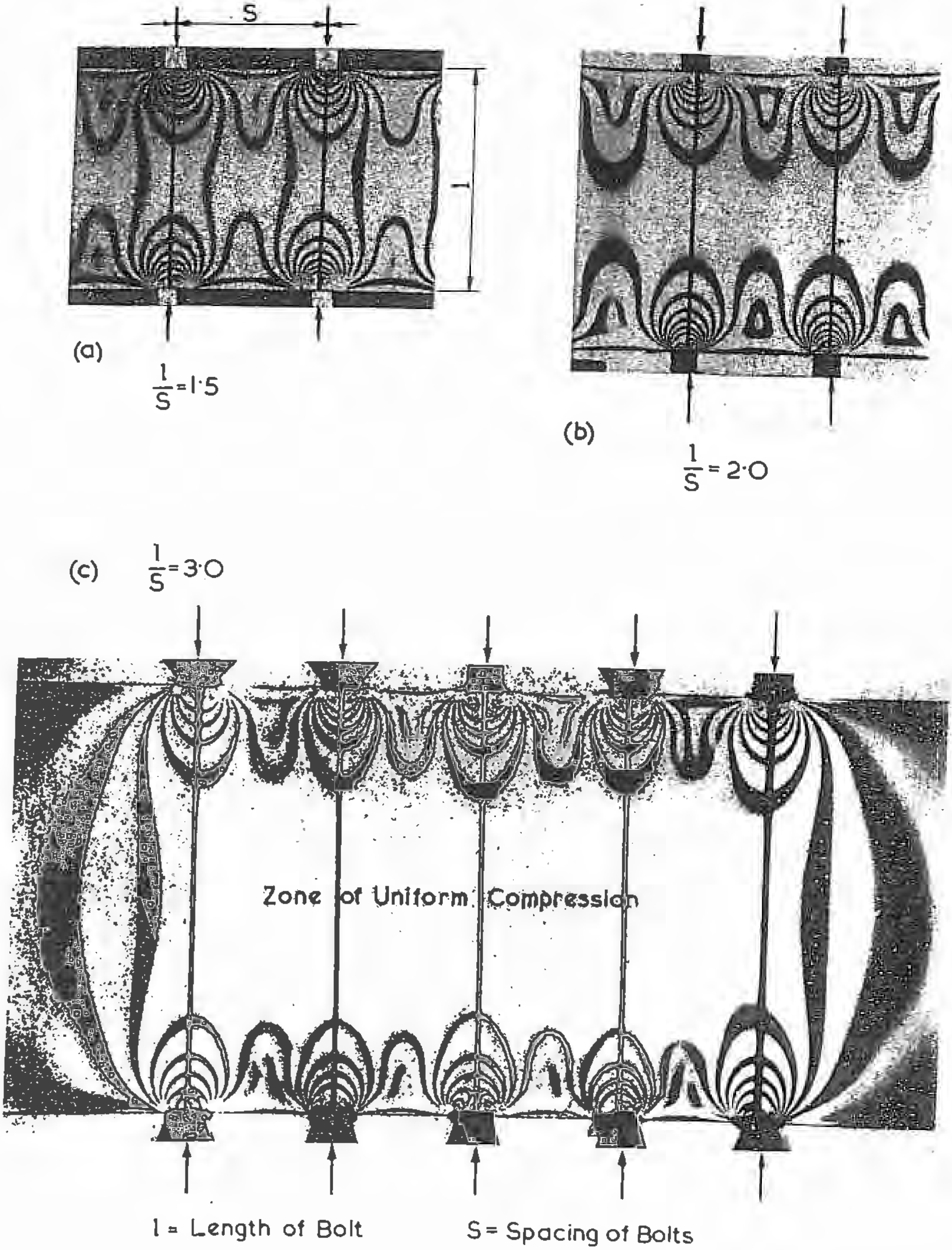
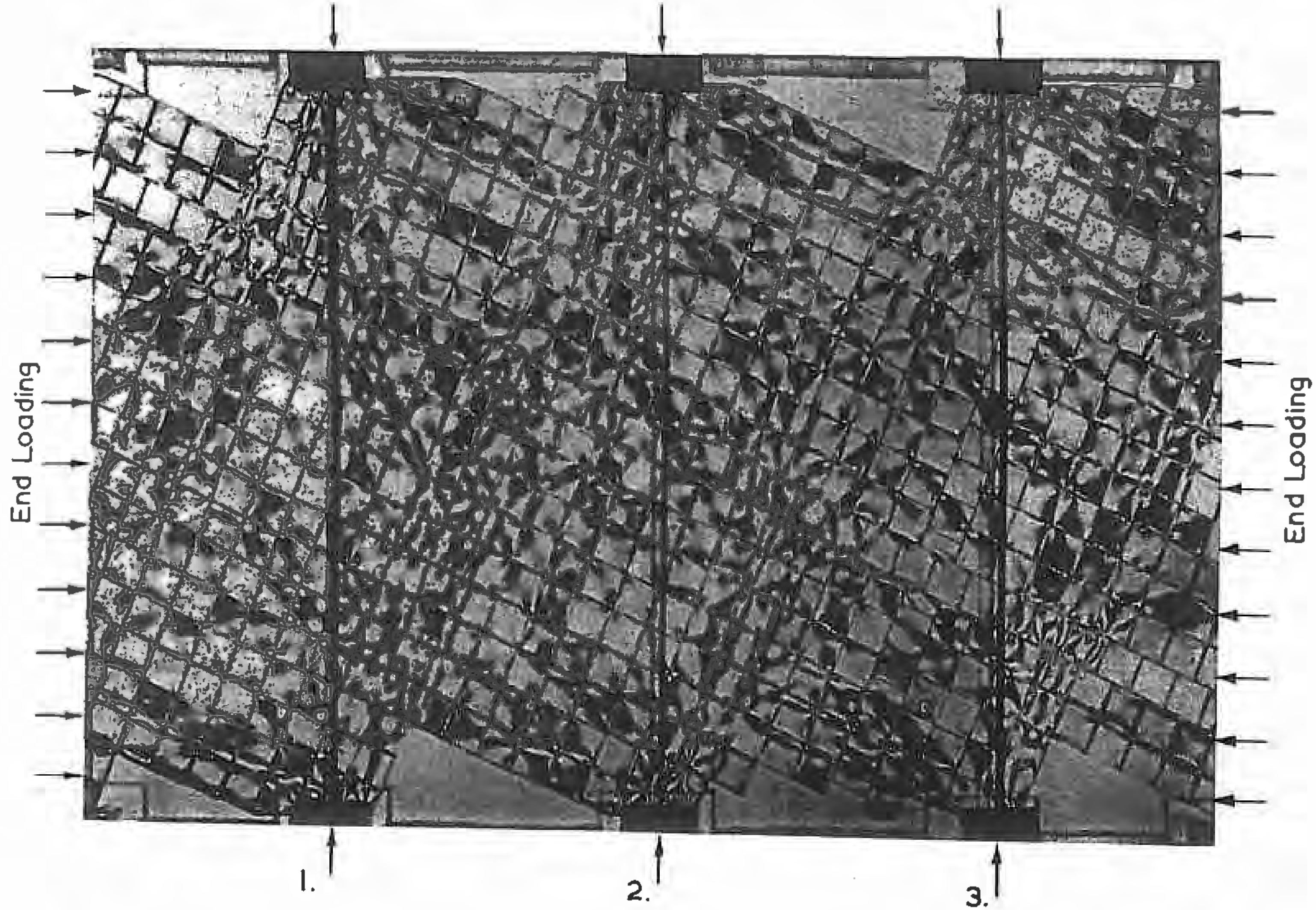
)) "Friction and Lubrication" by F.P. Bowden and D. Tabor. Methuen and Co. Ltd., London, 1956.



ROCK BOLT PHOTOELASTIC STRESS PATTERNS

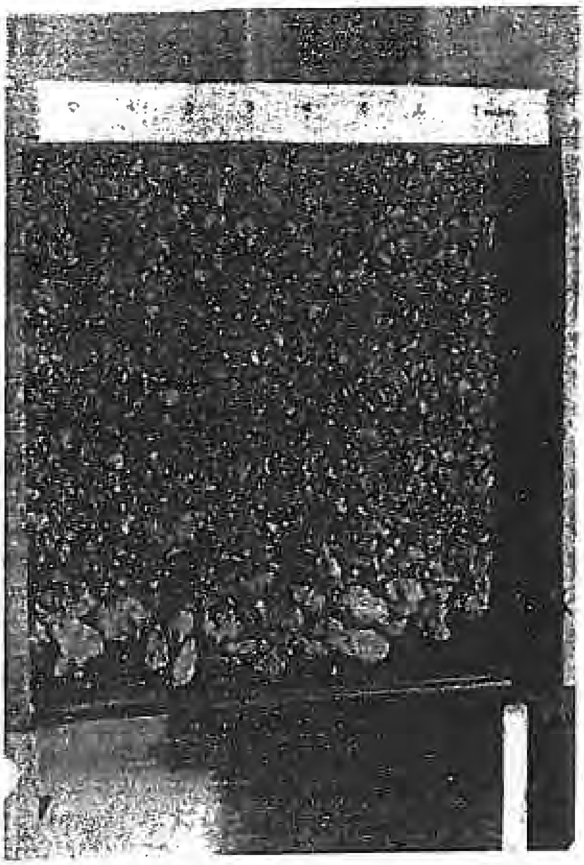
FIG. 18



Model Material: CR 39 Plastic. Number of pieces: 800. Size: 8" x 5" x $\frac{1}{4}$"

PHOTOELASTIC ROCKBOLT MODEL OF REGULAR JOINT PATTERN

FIG. 19.



(a) BOX MODEL

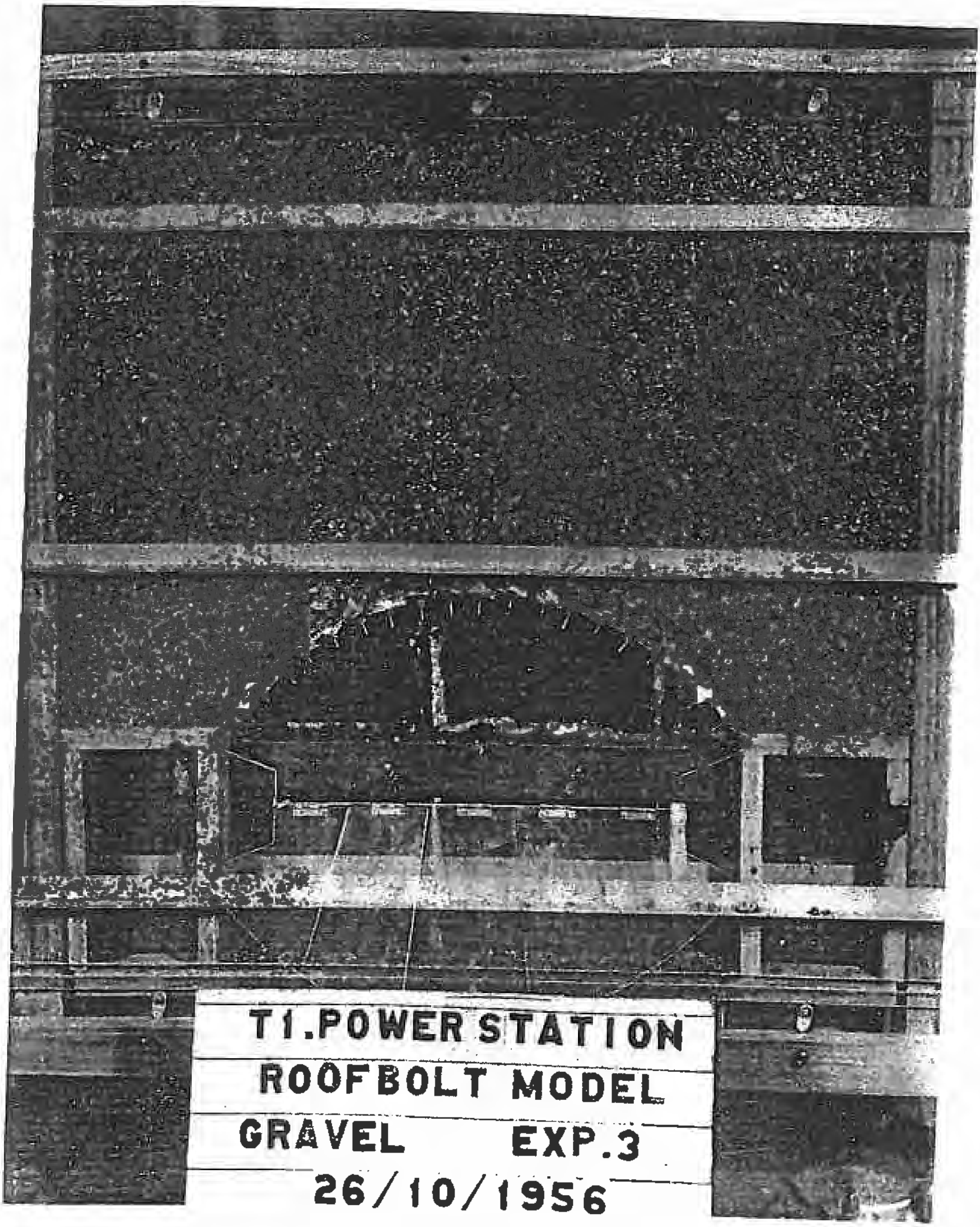
(c) BUCKET MODEL

(b) BOLTED SURFACE OF BOX MODEL

(d) BOLTED SURFACE OF BUCKET MODEL

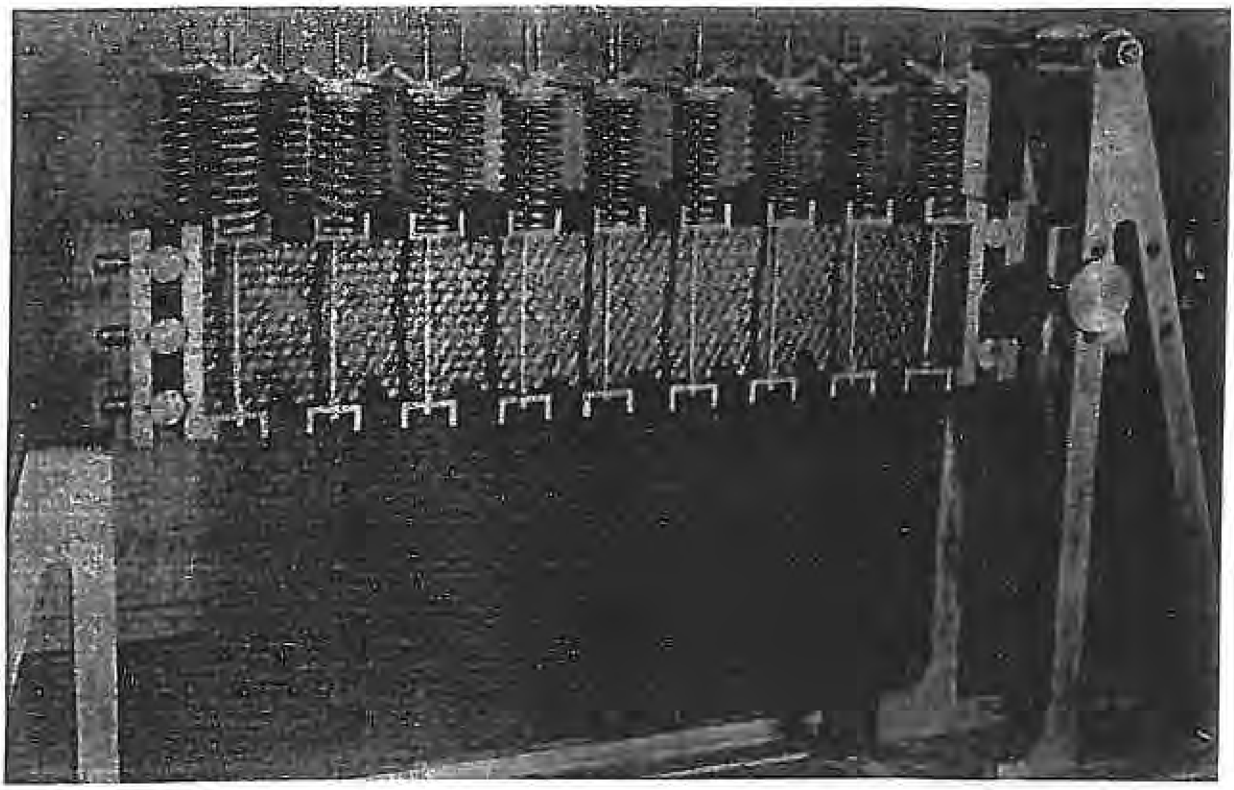
CRUSHED ROCK MODELS

FIG. 20

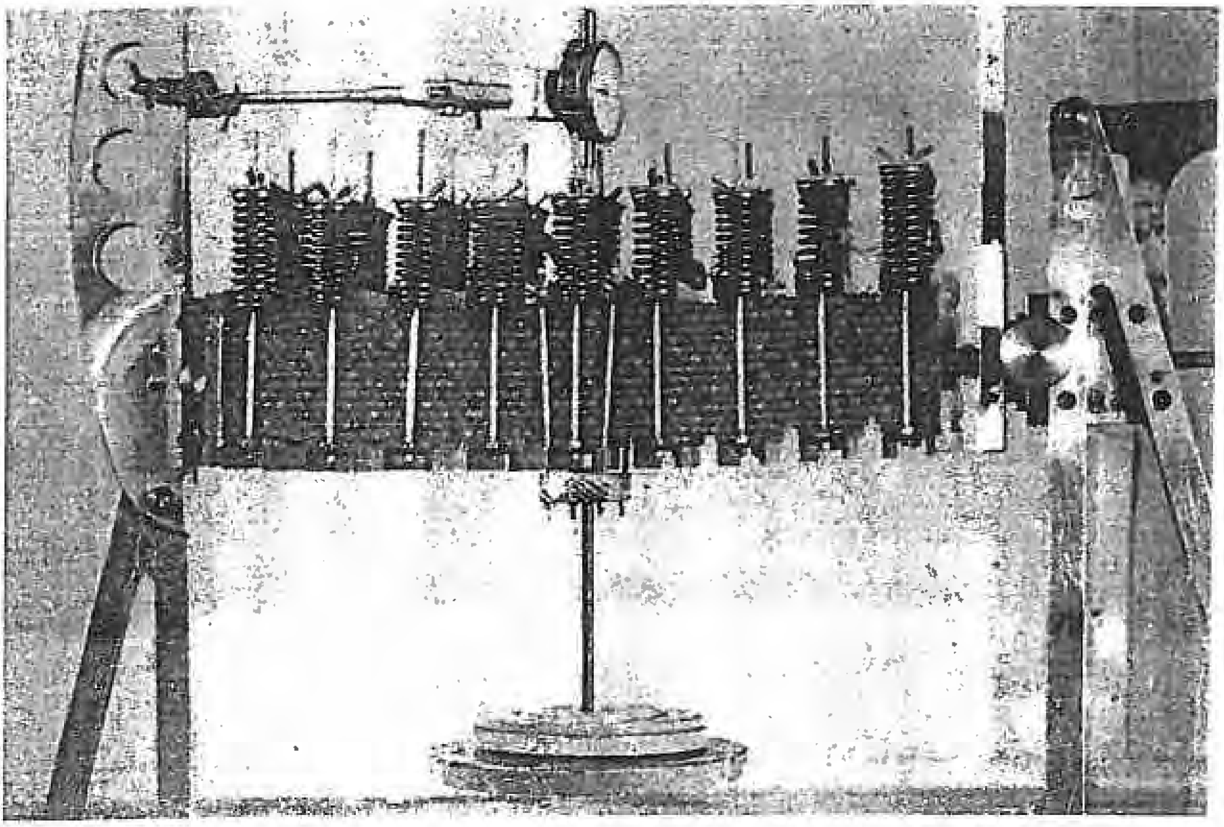


CRUSHED ROCK MODEL OF
MACHINE HALL ROOF

FIG.21



(a)



(b)

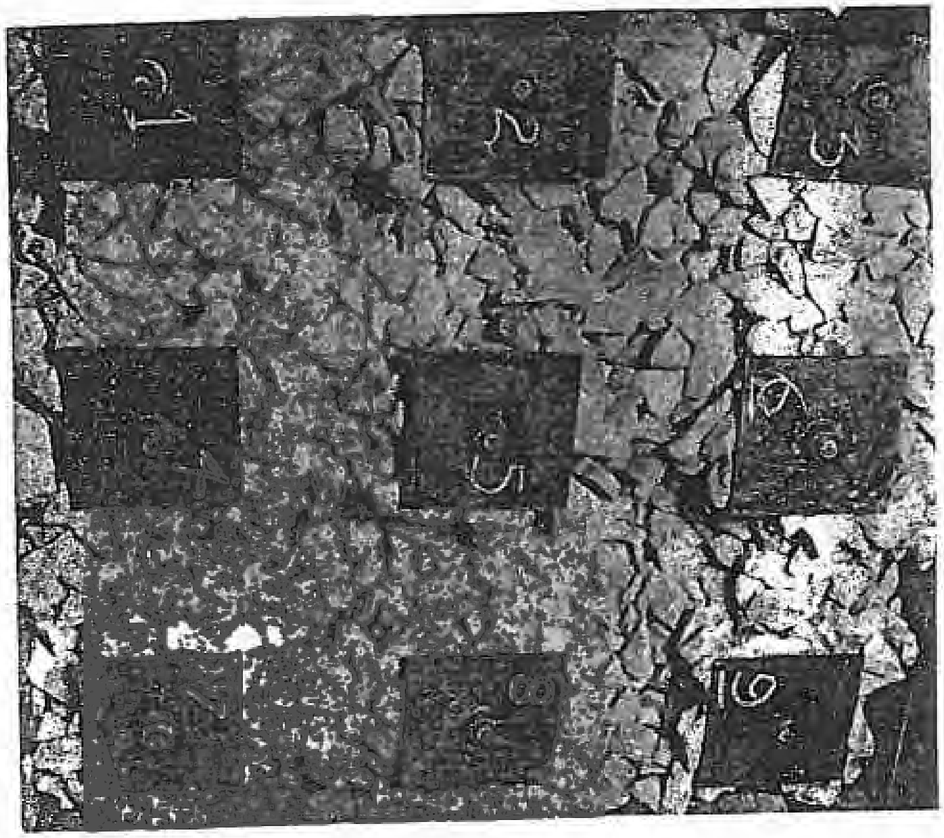
ROD MODEL

FIG.22

ROCK BOLT TESTS - CRUSHED ROCK

FIG. 23

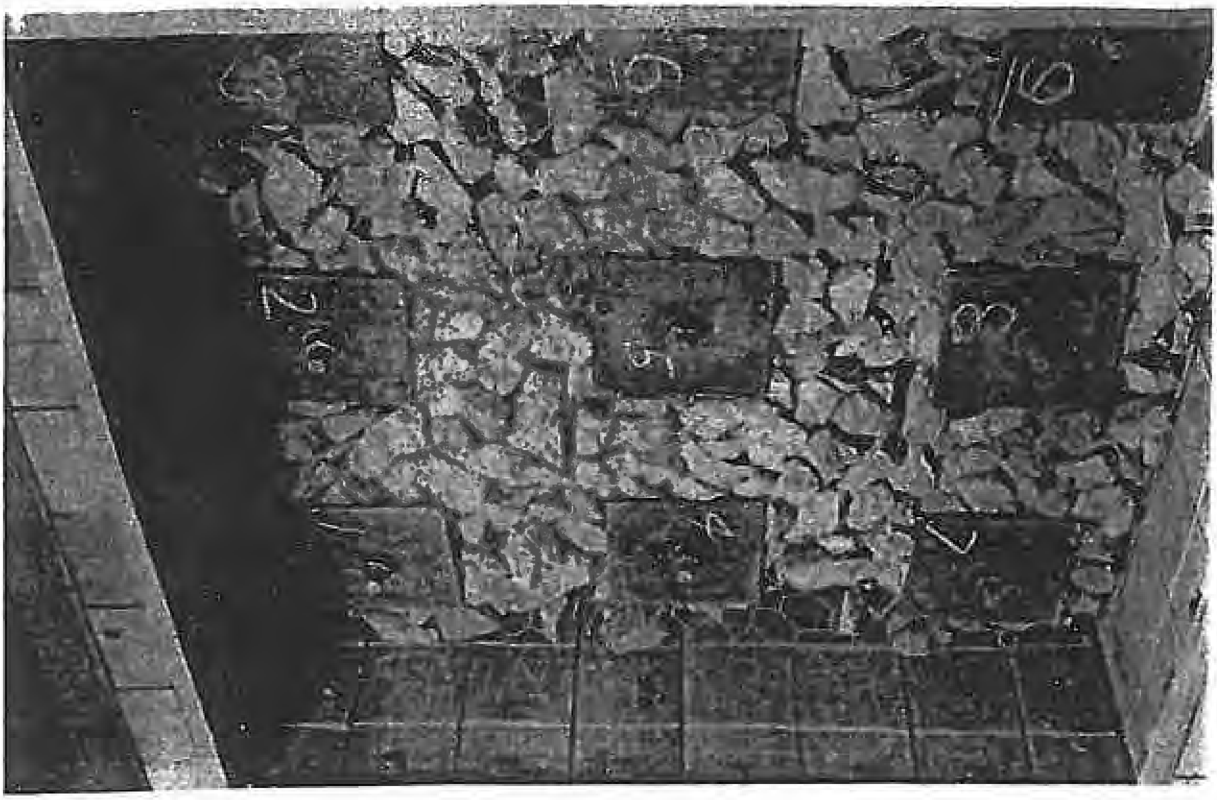
(a) Crushed Rock 3"–5"



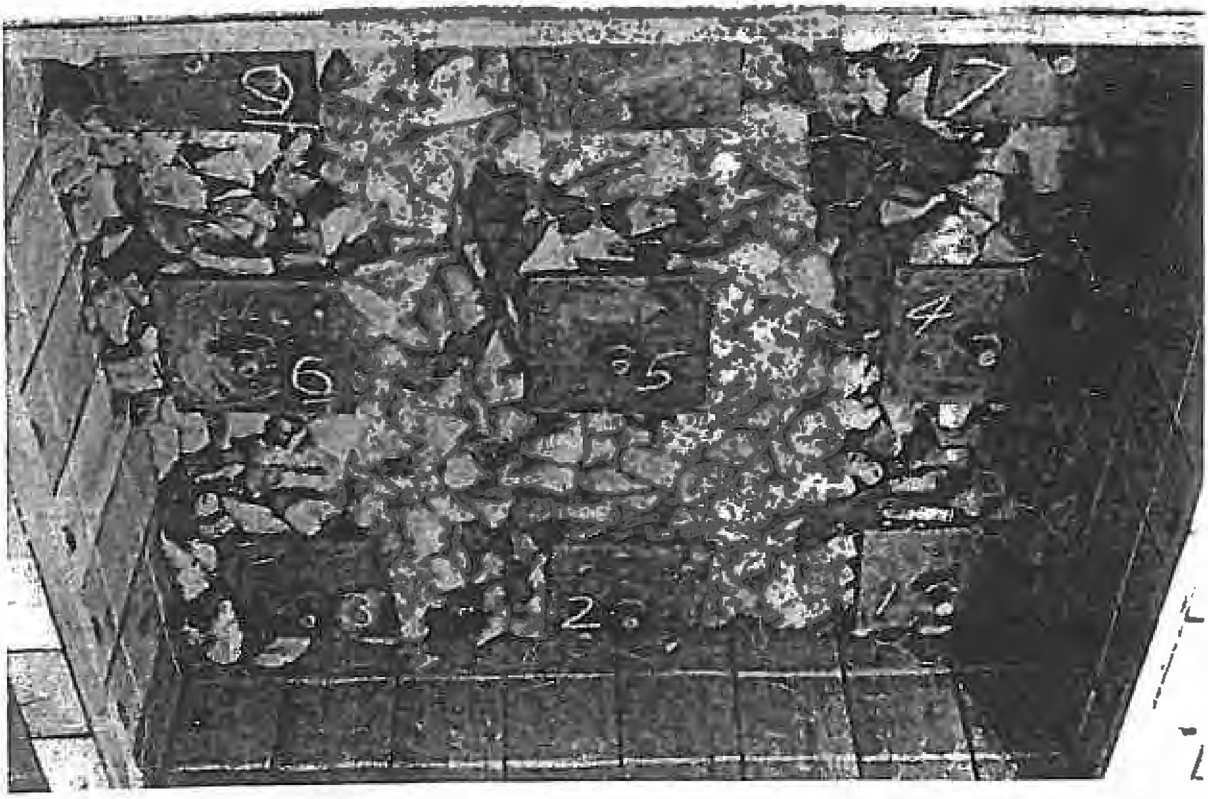
(b) Crushed Rock $1\frac{1}{2}$"–$2\frac{1}{4}$"

ROCK BOLT TESTS

FIG. 24



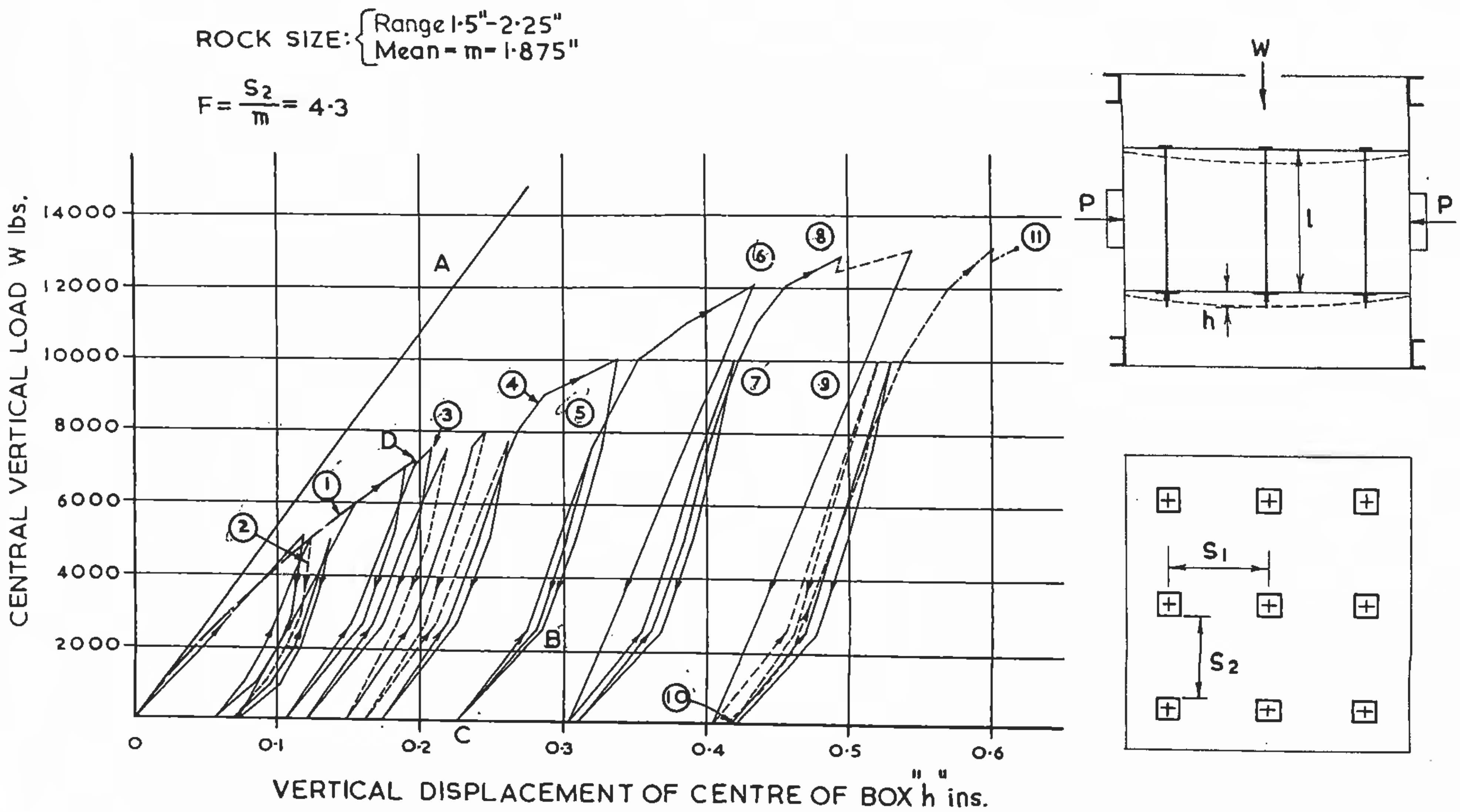
(a) Crushed Rock $1\frac{1}{2}$"$-2\frac{1}{4}$"; 2"x 24g. Wire Netting



(b) Wire Netting removed at Load of 13000 lbs.

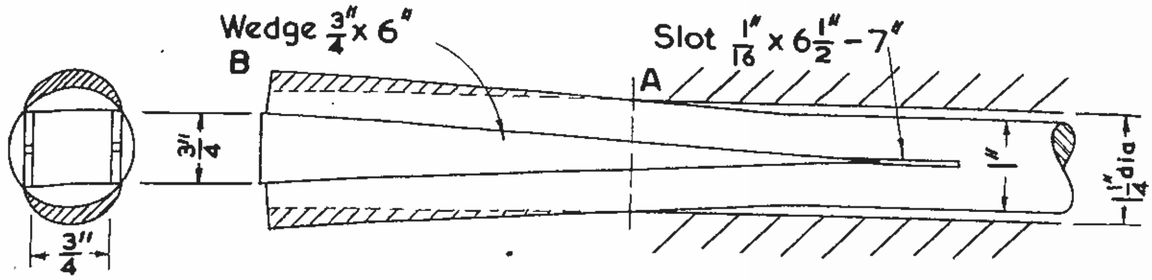
ROCK BOLT TESTS

FIG. 25

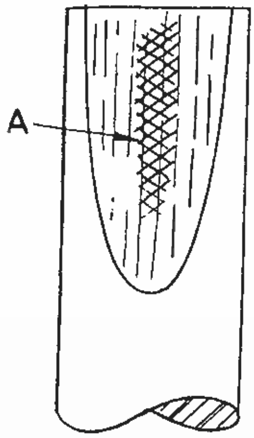


BEHAVIOUR OF CRUSHED ROCK MODEL

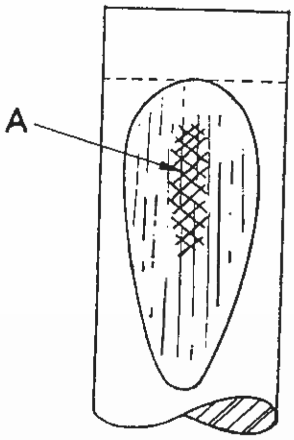
FIG. 26



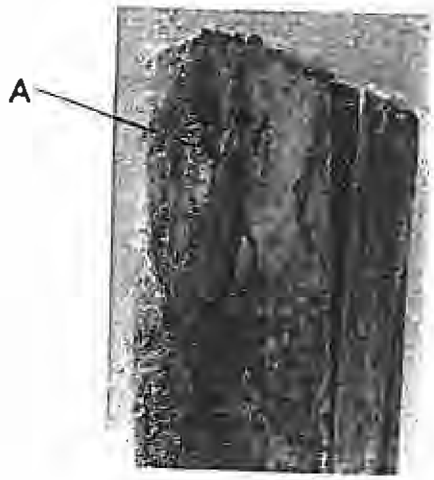
(a) TYPICAL ROCKBOLT



(b)

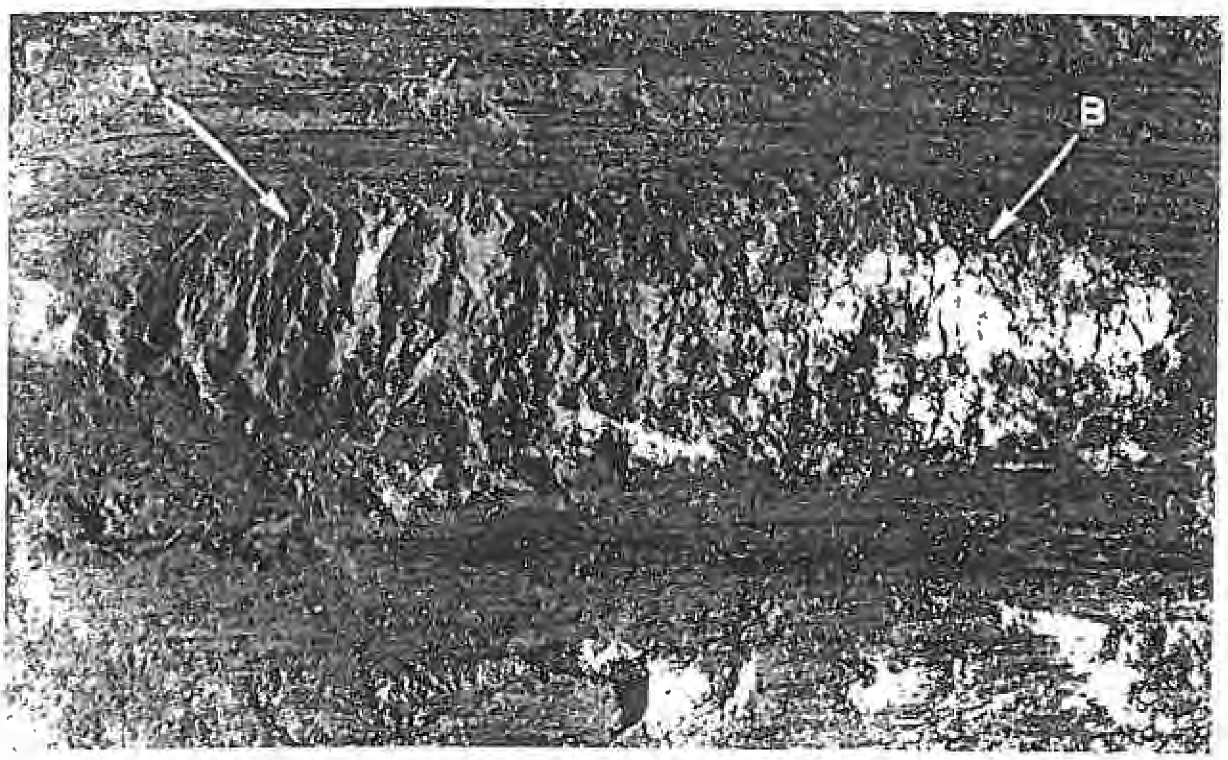


(c)



(d)

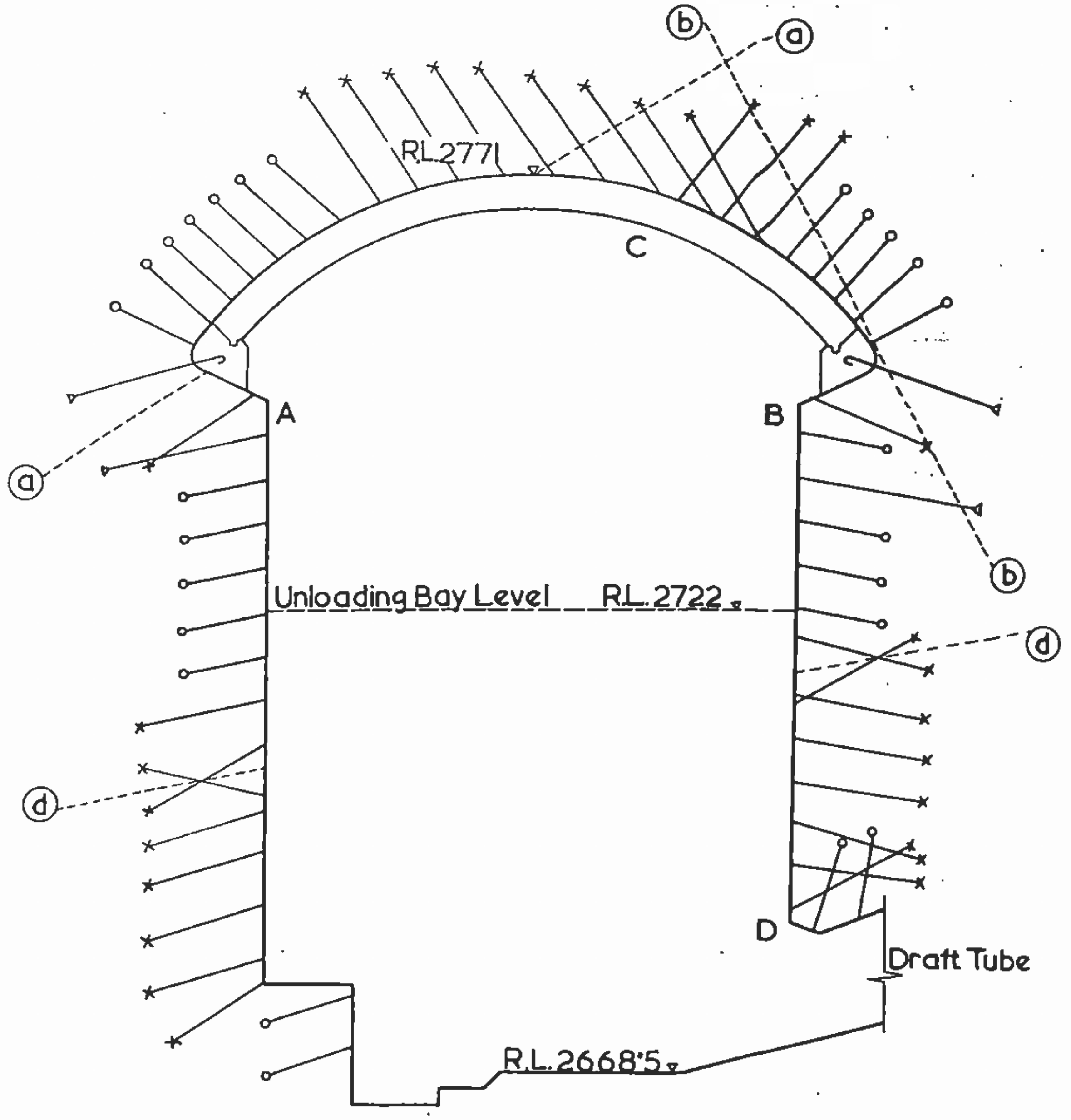
CONTACT AREAS



(e) CONTACT AREA OF (d)

SLOT AND WEDGE ROCK BOLT ANCHORAGE

FIG. 27



o - 10' Rock Bolts
x - 15' " "
△ - 20' " "

Notes: 1. Rock bolts in walls were grouted
2. Pattern of Bolts 5'x5' approx.

ROCK BOLTING IN MACHINE HALL

FIG. 36

APPENDIX D – CLAIM TO UNIQUENESS: PUBLICATIONS(EXTRACTS) (2)

THE SNOWY MOUNTAINS SCHEME PHASE 1 – THE UPPER TUMUT PROJECTS

Book "The Snowy Mountains Scheme" by Walter Diesendorf, 1961 Horwitz, extract pp52-58.

The Snowy Mountains Scheme

PHASE 1 — THE UPPER TUMUT PROJECTS

Edited by W. Diesendorf
D. TECH. SC., M.I.E. AUST.
Snowy Mountains Hydro-electric Authority

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PRINTED IN AUSTRALIA BY HALSTEAD PRESS, SYDNEY

the hoist cables in two layers. To compensate for the different, and the variable stretch-characteristics and speeds of the two cable systems, the lower end of the multi-core cable hangs beside the cage in a short, free bight, lightly counterweighted, so that the variations merely affect the length of the bight.

Structural Behaviour Studies

The behaviour of the pressure shafts under load is under observation so that the design assumptions can be verified and, if desirable, refined for future pressure shafts.

Only one pressure shaft was instrumented as the behaviour of the second shaft is expected to be very similar because of the close proximity of the two shafts and the comparable rock conditions. Strainmeters are attached to the outside of the steel lining near the upper and lower bends. The pressure of the groundwater around the shaft is measured by pore pressure cells installed near the strainmeters. From these instruments, cables lead to terminals in the top and bottom construction adits where the readings are made.

When the pressure shafts are filled, the steel lining expands and some of the load is taken by the concrete and the rock. When the pressure in the shaft is reduced, either by lowering the water level in Tumut Pond or draining the shafts, the steel lining contracts but corresponding recovery of the backing may not occur. In this case a gap may open between the steel liner and the concrete which increases the vulnerability of the steel liner to buckling by external water pressure. The stress in the steel lining and the magnitude of the gap were computed from measurements of strain in the steel lining.

During the commissioning of the power station the pressure shafts were filled and drained a number of times while testing the operation of mechanical equipment, and opportunity was taken to read the strainmeters and pore pressure cells for various water levels in the shaft. The measurements showed that the steel liner takes about one-third of the internal pressure, while two-thirds are taken by the concrete and rock backing. The width of the gap as derived from these measurements was of the same order as anticipated from similar measurements on overseas pressure shafts. The groundwater pressures at the locations tested were negligible. The results were very satisfactory as they showed consistency between observation and theory.

Pressure Shaft Guard Gates

As previously indicated, the headwater surge tank risers serve also as the gate shafts for the two gates at the entrances to the pressure shafts. The gates have two functions—they act as isolating gates to permit the pressure shafts to be dewatered selectively for inspection or repair, and as guard gates to close against full flow in an emergency. By cracking open the gates, they are also used to refill the shafts after a dewatering operation.

Each gate is effectively 10 ft. 3 in. wide by 15 ft. 3 in. high, and withstands a water load of 1,525 tons under the maximum operating head of 350 ft. The gate leaf is of massive riveted construction and, to minimize the friction of such a load, has six steel wheels on each side which run on tracks embedded in the concrete. Composite gate seals of rubber and bronze are used.

Each gate is raised or lowered by a hydraulic hoist (fig. 3.22) mounted in the upper surge chamber, the gate and hoist being connected by a series of 8 in. dia. pin-jointed steel rods totalling some 340 ft. Each hoist, which is operated by oil pressure, has a lifting capacity of 600 tons in order to control effectively not only the dead weight of the gate and stem but also the drag of friction forces on the gate and the very substantial hydraulic downpull which acts on the gate when partly open.

The gate is controlled from a cabinet beside the hoist. For safety reasons, it can be opened only at this cabinet but it can be closed, in emergency, by remote control from the power station, either by push-button or by certain automatic protective devices. Since the gate must be ready at all times for emergency closing, it is held open by oil pressure beneath the hoist piston; and there is, of course, some tendency for oil to leak past the piston, thereby allowing the gate to move slightly from its fully open position. However, as soon as the gate has sagged in this way by a few inches, an automatic device starts the oil pump which restores the piston to the fully open position.

POWER STATION

The power station is the hub of the whole project for it is here that the energy of the high-pressure water is converted into electrical energy at high voltage.

The principal structures of the power station are two large underground halls which house the turbine-generators, the transformers and all ancillary and control equipment.

The arrangement of these halls and other underground chambers, of the water passages and the tunnels connecting to the surface is shown in figs. 3.24 and 3.25.

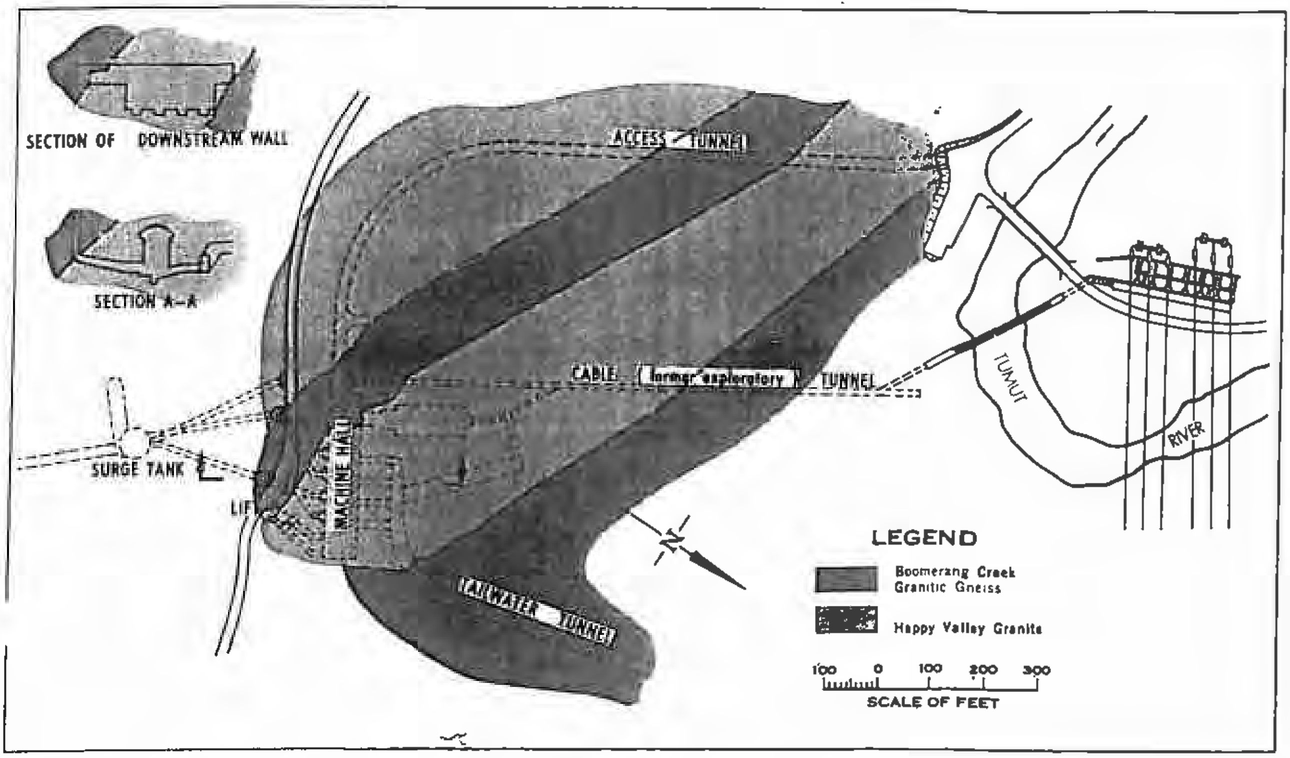


FIG. 3.23. Tumut 1 Power Station. Geological map.

Geology

The rock mass surrounding an underground power station becomes a structural element whose properties and characteristics under load are of vital importance; geological conditions were therefore very carefully explored.

In the first stage of the investigations, four sloping diamond drill holes, varying from 1,000 to 2,000 ft. in length, were put down from the surface to power station level. The rock samples brought to the surface indicated that there was a sufficiently large block of sound rock for the power station at the required level 1,000 to 1,200 ft. below. In order to confirm these results and to obtain further information on the detailed structure of the rock, an exploratory tunnel, 1,100 ft. long, was next driven into the site from the floor of the valley; and from chambers near the end of the tunnel, six diamond drill holes with a total length of 1,380 ft. were drilled across the proposed machine hall and draft tubes.

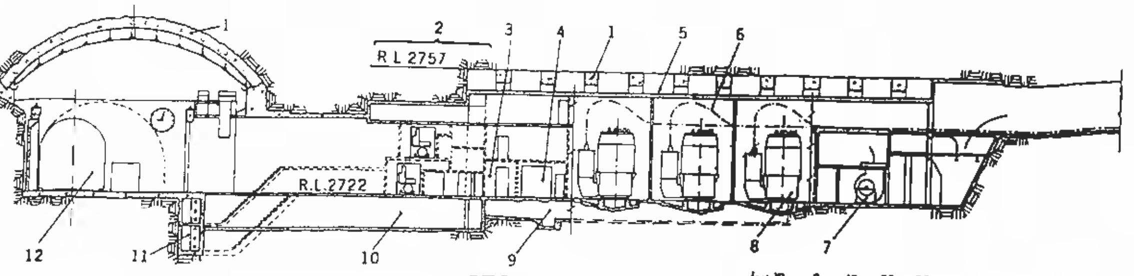
The rock at the site is granite and granitic gneiss. The granite is in the form of sheets 100 to 300 ft. in thickness which are inclined at 40 to 50 deg. from the horizontal and are intrusive into the gneiss (fig. 3.23).

Both rock types are hard and strong and the samples cut from diamond drill cores gave the following laboratory figures:—

- Unconfined compressive strength, approx. — 20,000 lb/sq. in.
- Tensile strength, approx. — 1,000 lb/sq. in.
- Young's Modulus — 6.5 to 10 x 10^6 lb/sq. in.
- Poisson's Ratio — 0.2 to 0.25

In its natural state the rock mass contains three systems of parallel fracture planes or joints which are at approximately right angles to each other; at the power station site the rock is also intersected by several small faults. These defects considerably reduce the strength of the rock in situ, in comparison with the strength measurements derived from small samples of unjointed rock.

The gneiss, although similar to the granite in many respects, was much more closely jointed. It was judged that the power station could be built in either rock type, but that the large halls would probably be easier to construct in the granite where fewer supports would be required. When the rock was exposed by a pilot drive through the machine hall, it was found that the quality of the granite was superior to that anticipated from the drill cores. The pilot drive was extended, for further exploration,



Above: FIG. 3.24. Tumut 1 Power Station. Sectional elevation of transformer hall. 1: Concrete roof ribs. 2: Switchgear cells. 3: Compressed air room. 4: Oil treatment room. 5: Concrete shell ceiling. 6: 330 kV cable. 7: Ventilation fan. 8: Step-up transformer. 9: Transformer oil drainage sump. 10: Pipe and control cable duct. 11: Busbar duct. 12: Access tunnel.

Right: FIG. 3.25. Tumut 1 Power Station. General arrangement and sectional elevation of machine hall. 1: Concrete shell ceiling. 2: Corrugated iron ceiling. 3: Expansion joint. 4: Concrete roof ribs. 5: Concrete roof abutment beam. 6: Crane runway beam. 7: Overhead travelling crane. 8: Control room. 9: Workshop. 10: Cable and ventilation gallery. 11: Access gallery. 12: Rotor poling pit. 13: Storage area. 14: Connecting tunnel. 15: Switchgear cells. 16: Compressed air room. 17: Oil treatment room. 18: Pipe and cable duct (busbar duct above). 19: Step-up transformer. 20: Ventilation plant room. 21: Tailwater surge tank, upper chamber. 22: Tailwater surge tank, lower chamber. 23: Draft tube.

70 ft. beyond the far end of the machine hall; and as more good granite was encountered it was decided to move the location of the station a distance of 70 ft. along the axis of the machine hall: this placed almost the whole excavation in the granite.

The original water table was 100 to 150 ft. below the surface, but inflows into the excavations of up to 3 cusecs caused the water table above the site to fall by 250 to 500 ft. It was considered important that the water table should be permanently maintained as low as possible in order to reduce the external water pressure on the pressure shaft linings; the free-draining of the rock mass into the excavations has therefore been preserved wherever possible.

Disposition of Main Excavations

The principal factors determining the layout of an underground power station are the space requirements of the equipment, the safety of the excavations, and the cost. To maintain the stability of the rock around individual excavations, it is desirable that dimensions be kept small; on the other hand, too many small excavations in close proximity could also be unsafe, and would tend to be more costly for the same usable total volume. A further requirement was that the long high walls of the main excavations should intersect the principal sets of joints and the granite/gneiss boundaries at large angles.

As a compromise between these various and somewhat conflicting conditions, the two largest walls—those of the machine and transformer halls—were placed at right angles to each other, and the much smaller tailwater surge chamber parallel to the machine hall.

By locating the control building and the assembly bay at opposite ends of the machine bays, it was possible to confine the deepest excavation to the central part of the machine hall, thus avoiding high vertical end walls.

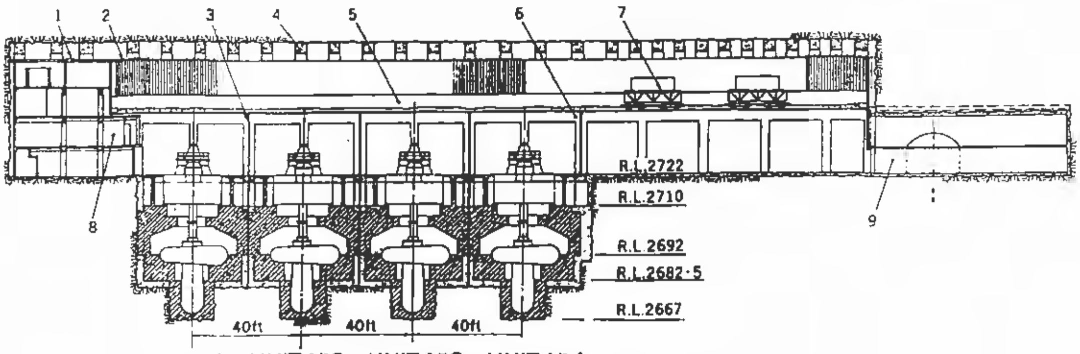
Intersection of the two large halls would have presented difficult problems of support, particularly in the early stages of construction; they were therefore separated by a connecting tunnel with the minimum cross section needed to accommodate the transformer passage and the busbar ducts.

Structural Analysis of Excavations and Behaviour Studies

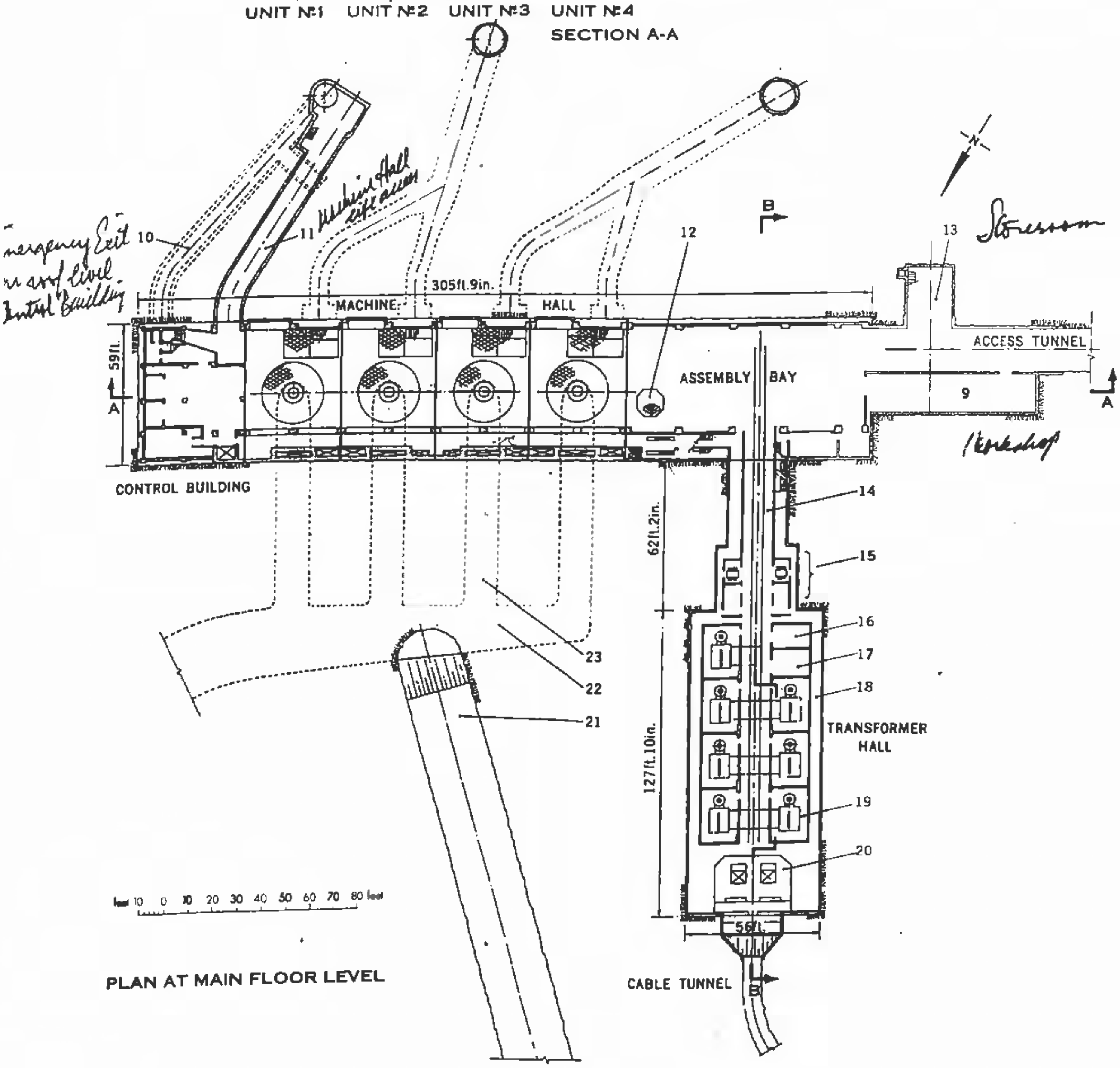
There is still much to learn about the behaviour of rock surrounding large underground excavations, and the opportunity was taken at Tumut 1 Power Station to initiate a programme of rock stress measurements and structural behaviour studies.

Actual rock stresses around excavations depend on the stress conditions in the native rock, the shape and dimensions of the excavation, and the geological structures present.

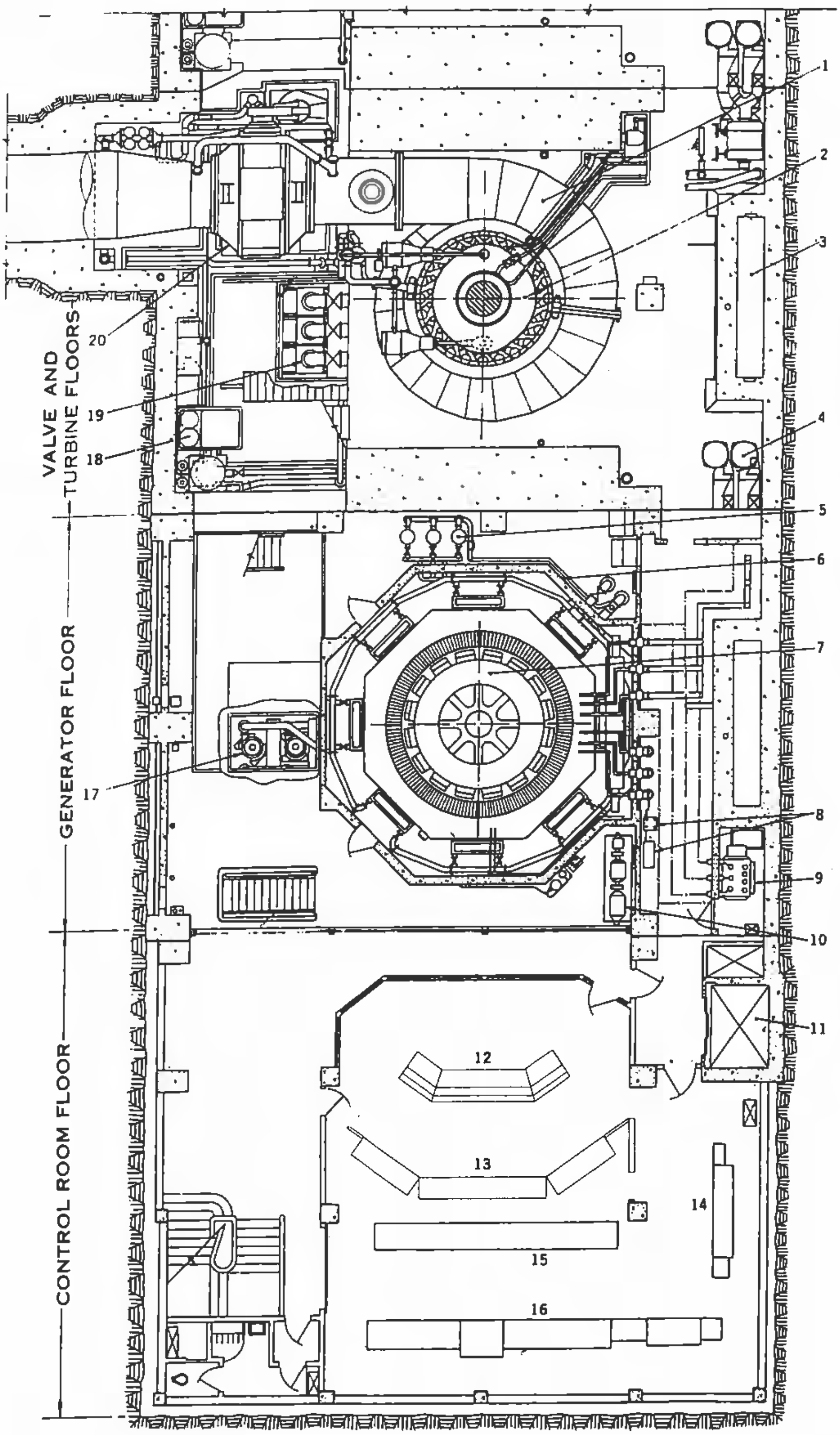
At an early stage in excavating, the actual stresses at selected points of exposed faces were measured, using the flat-jack method. The stresses in the undisturbed rock were deduced by correlating the actual stresses with the results of photo-elastic laboratory studies of the stress concentrations on two-dimensional models of the excavated cross sections. These studies disclosed an apparent anomaly; in that the horizontal stress field in the undisturbed rock was considerably larger than the weight of the overburden gave reason to expect, and was of near equal magnitude with the vertical stress field. The reason for this is open to surmise, but the large horizontal stresses may be 'locked up' stresses founded in the geological history of the region.



SECTION A-A

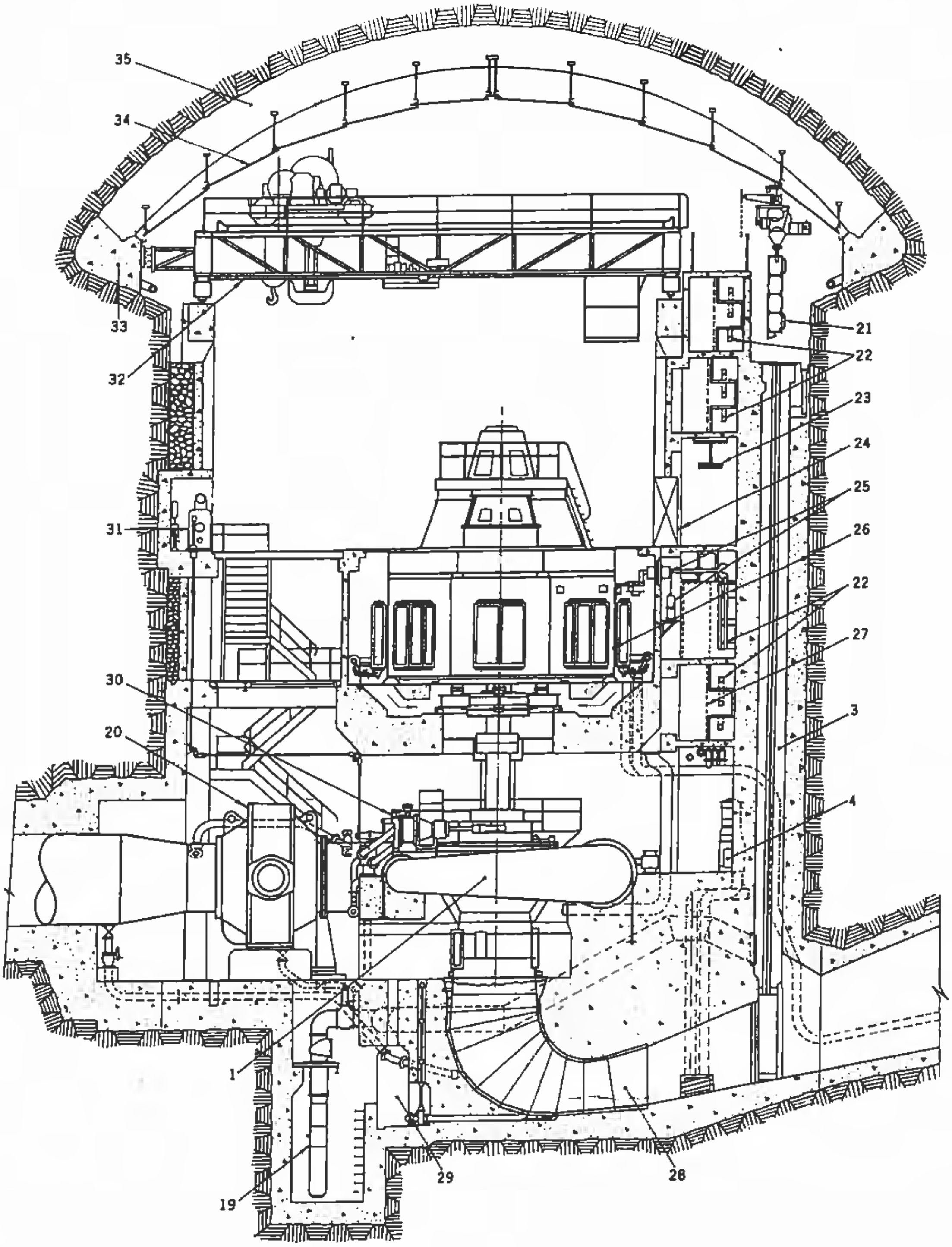


PLAN AT MAIN FLOOR LEVEL



Figs. 3.26 and 3.27. Plan (*left*) and sectional elevation (*right*) of machine hall.

1: Turbine spiral casing.
2: Regulating ring.
3: Draft tube gate slot.
4: Cooling water pump.
5: Oil-cooler for bearing oil.
6: Generator octagon.
7: Rotor.
8: Neutral earthing equipment.
9: Unit auxiliary transformer.
10: Impulse exciter set.
11: Control building lift.
12: Control desk.
13: Control board.
14: Metering board.
15: Protection board.
16: A.C. common services and D.C. distribution board.
17: Normal drainage pump.
18: Governor pumping set.
19: Emergency drainage pump.
20: Main inlet valve.
21: Draft tube gate suspended from hoist.
22: Generator-transformer connections.
23: Control cables.
24: Unit auxiliary board and local control panel.
25: Current transformer and lightning arrester.
26: Generator.
27: Expanded metal screen.
28: Draft tube.
29: Drainage gallery.
30: Guide vane servomotor.
31: Governor.
32: Overhead travelling crane.
33: Concrete roof abutment beam.
34: Galvanized iron ceiling.
35: Concrete roof rib.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Once the initial rock stresses were known, the effect of the progress of the excavation on the stress distribution around the machine and transformer halls was studied by the photo-elastic method. These investigations showed that the worst stress conditions should occur at the first stage when the roof excavation was completed down to the springing line. Maximum compressive stresses were predicted at the corners of the excavation for the roof abutments, with almost zero stress at the crown; but continuing excavation below the springing line would reduce the stresses at the abutments and cause increased compression at the crown. It was concluded that, if the rock was stable at the first stage of excavation, no troubles need be expected as the excavation proceeded downwards.

The photo-elastic studies were extended to forecast the behaviour of the concrete roof ribs during excavation. Confirmatory evidence was required to support these theoretical investigations, and the following measurements were therefore taken during the excavation and construction of Tumut 1 Power Station.

- Measurement of strain in the reinforced concrete arch ribs by means of electric resistance-type strainmeters embedded in the concrete, and Huggenberger deformeter points fixed to the sides of some of the ribs.
- Measurement of rock and concrete movements during construction by means of sensitive level clinometers and by precise survey methods.

Although measurements still continue, it has been established that the field measurements of the behaviour of the roof ribs are in good agreement with forecasts from the photo-elastic studies.

Use of Rock Bolts

During the design of the power station it was decided to use rock bolts as the primary construction support for the roof and walls of the machine and transformer halls. This decision was a bold one, as rock bolts had not been previously used to any extent in Australia for civil engineering works, and certainly not in excavations of the magnitude proposed for Tumut 1 Power Station.

Over the preceding decade, rock bolts had come into prominence as a means of support in coal mines and other excavations in sedimentary rocks. Little, however, had been published on their use in igneous and other hard rocks. A programme of laboratory and field investigation was undertaken in order to obtain some basic information on the action of rock bolts in a rock mass, on the performance of the different types of anchor in the harder types of rock, and on the value of different installation procedures.

In the granites of the Snowy Mountains Area, the continuity of the rock is broken by systems of joints, spaced from a few inches to several feet apart. Adjoining blocks of rock interlock by virtue of surface irregularities. If, because of the effect of excavation in the vicinity, these joints were allowed to open up, the blocks would be able to move in relation to one another and this could result in a fall of rock into the excavation. The purpose of rock bolting is to hold the joints together so that they will stay solidly in place as in a masonry wall.

To be effective, rock bolting has to be carried out as soon as possible after excavation as the joints have a tendency to open up gradually because of readjustment of stresses.

The mechanics of rock bolting were first studied on laboratory models using various materials for the blocks: wood with plain and notched sides, wax, glass rods and crushed stone. A striking demonstration of the effectiveness of rock bolts was given by supporting an arch made up of ordinary glass marbles, a material chosen as an example of minimum mutual adhesion.

In parallel to the model tests, photo-elastic studies were made to investigate the stress conditions caused by rock bolts. All these tests threw much light on the questions of optimum tension, length and spacing of the bolts and the desirable angle in relation to the free surface.

To obtain information on the effectiveness of different types of rock bolts and rock bolt anchors in the particular rock conditions of the Snowy Mountains Area, some 300 test bolts were installed at two sites—one a cliff face on the surface and the other a disused access tunnel. These bolts were tested by applying a tensile force to the projecting head of the bolt until the anchor failed or the bolt broke.

As a result of these investigations and the very satisfactory behaviour of rock bolts as a support during construction, it became apparent that they would be an economical permanent support of great use in many places, if preserved against corrosion. Of the various means of preserving the bolts, that of grouting them into the holes was the most attractive. The equipment and procedures which would do this effectively and cheaply were soon developed, and grouting of rock bolts has since become an everyday procedure.

Grouted rock bolts offer very great advantages over and above simplicity and economy. The grouted rock bolts and the rock form in effect a kind of prestressed structure surrounding the excavation, which provides an ideal solution to the problem of ensuring stability of the tunnels and other excavations.

APPENDIX D – CLAIM TO UNIQUENESS: PUBLICATIONS(EXTRACTS) (3)

VOICES FROM THE SNOWY

Book "Voices From the Snowy" by Margaret Unger, 1989 NSWUPress, extract pp 134-137 & refs.

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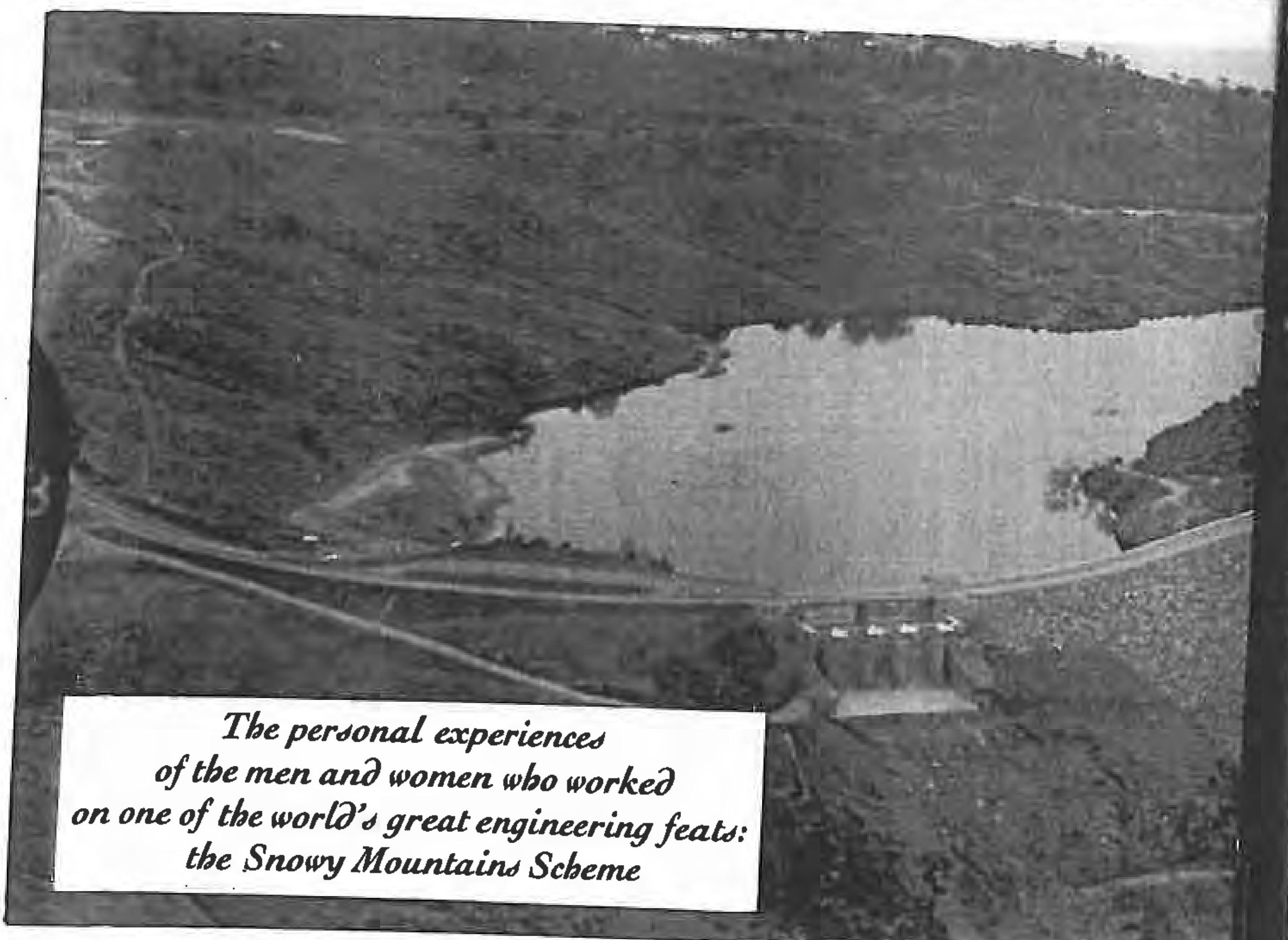
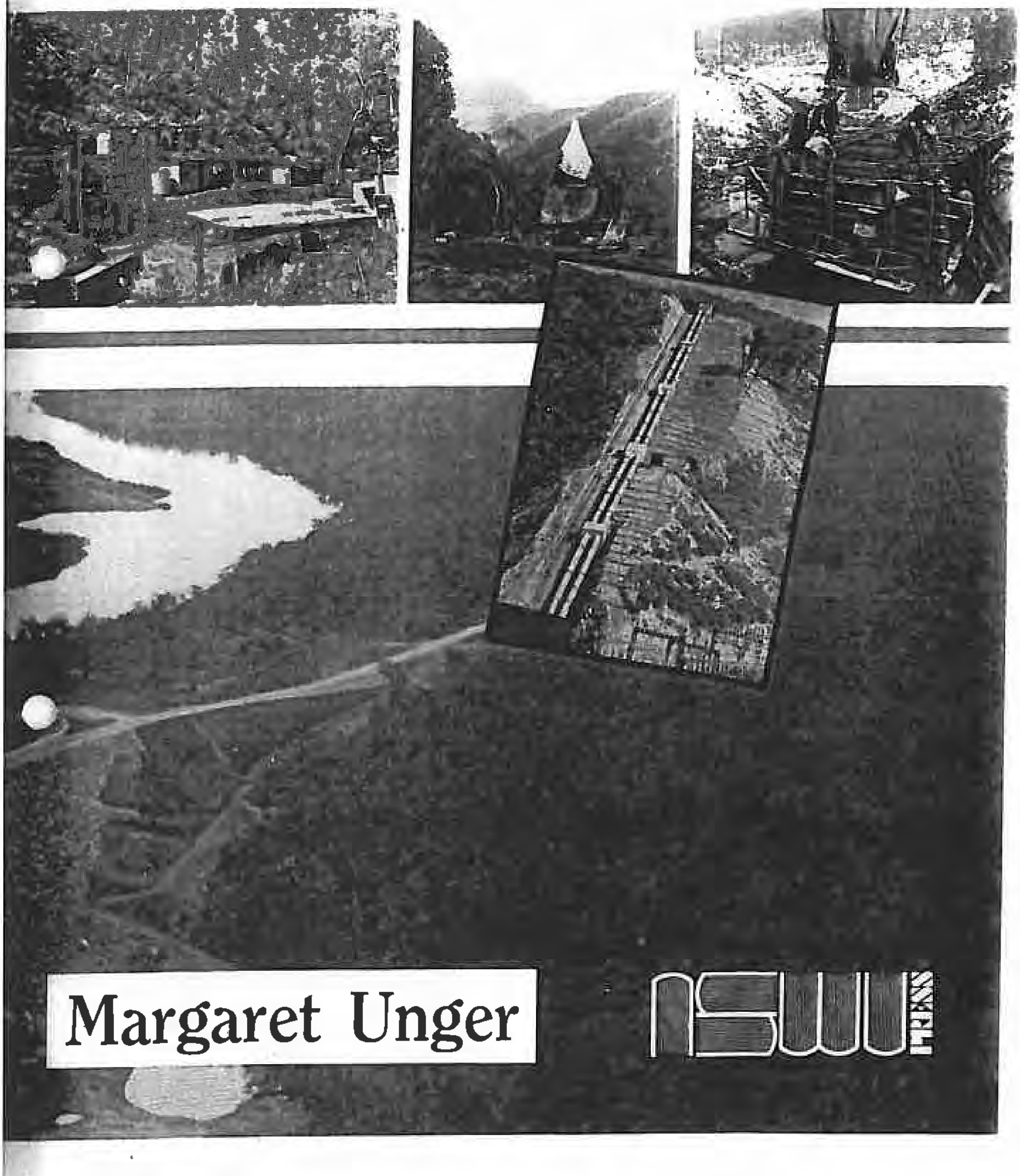
VOICES FROM



The personal experiences of the men and women who worked on one of the world's great engineering feats: the Snowy Mountains Scheme

THE SNOWY



Margaret Unger

Rock stress instrumentation switch box in the survey niche of Tumut 2 power station machine hall showing a reading being taken with a Carlson test set.

"The need for looking into rock mechanics came up during the investigation stage for the T1 power station. This power station is 1000 feet [305m] underground and not much was known of the stresses in the rock at that depth,nor what would happen to the rock when a big opening was cut into it. Of course the first way of finding out what is happening is to take measurements. Therefore teams from the Authority's Scientific Services division went down into the access tunnels and measured the actual rock stress, that is, the pressure acting on the rock due to overburden, the load of the rock and the tectonic history which means what happened hundreds, thousands and millions of years ago.

There were no methods known elsewhere which were suitable for the work in the Snowy Mountains, therefore we had to develop our own techniques. We discovered that the rock stresses were different from what had been assumed. It had been assumed that the pressure was essentially vertical with small horizontal pressures; the measurements showed that the horizontal pressures—the frozen-in stresses from the tectonic history of the area—were much bigger than assumed and that they were about the same size as the vertical stresses. So that was a feature that had to be considered in the design of the T1 power station.

When Tumut 2 power station came into the design stage, we were better prepared and a more sophisticated approach was made. The rock stress measurements were carried out in the access tunnel in relatively greater detail and predictions were made on the behaviour of the excavation as work proceeded. This was done by making models with photoelastic material which could predict what would happen to the rock when this big excavation was carried out. This preliminary work was followed up by measurements taken during excavation. There was very good agreement between what was predicted and the actual behaviour of the power station. Considerable savings were involved in the roof support which could now be made much thinner because we knew the reaction of the rock to the excavation. The results of this work became known elsewhere and caused general interest throughout the world."[31]

It was about this time that the Authority took steps to ensure their structures were designed not only to be efficient and economic but also to be aesthetically pleasing. 'We realised,' says Hudson, 'that engineers were all inclined to think that safety and minimum cost of structures are the beginning and end of things: we didn't pay enough attention to appearances. So we decided to do something about it.'[2] A three-man committee was set up, the appointees being Professor Dennis Winston, the Authority's Chief Engineer (Civil Design) Ivor Pinkerton and Architect Donald Maclurcan. Not only were the aesthetics of the actual structures studied by the committee but also the surroundings: the landscape work around the structure, everything in any way connected with the structure went through the committee's vetting and approval. Donald Maclurcan:

"This was not normal at that time. Since then of course, society is generally more enlightened in these matters and very few major engineering structures are developed without the combined disciplinary approach.

One of the ideas I had was that the construction of these giant underground power stations was defective when it involved an attempt to make them feel like buildings, with false windows and false light coming in through these windows. Tumut 1, the first of the underground power stations, was constructed with walls and lighting effects. I remember talking about this with Bill Hudson. I suggested that for the next station we just express the structure, excavate the great hole and let the bare granite walls be seen. Hudson explained that there were problems. There would, for example, be water on the walls. 'Let there be water,' I replied. 'Let it be just like a hole in the ground.' I might say I don't claim any originality for my ideas, and in expressing my beliefs I quoted other works which had been carried out like this in France. Hudson thought about all this for some time and eventually he agreed that this next power station, T2 it was, be designed in accordance with my recommendations."[56]

On 10 March 1963 the *Sunday Telegraph* described the Queen's visit to Tumut 2:

Geehi airstrip (centre left) among the foothills on the western side of the Snowy Mountains.

"The underground Machine Hall ... is like a setting for a futuristic movie. It is 320 feet long, 51 feet wide and 110 feet high [98m x 16m x 34m approx.] and brilliantly lighted.

With a touch of imagination, the engineers have left the natural granite walls framed in the huge wall panels.

'Was it because you had to, or was it by design?' the Queen asked Chief Electrical Engineer Callinan after commenting on the superb effect.

'By design,' Mr Callinan replied."

The intensive labour involved in lining tunnels with concrete is seen here as reinforcing steel is placed in a section of the Jindabyne-Island Bend tunnel.

The bare rock walls of the T2 underground power station give visitors an opportunity to see the Authority's innovative use of rock bolts. Rock bolts are a fairly inexpensive method of strengthening areas of broken rock which, if left without reinforced concrete lining, would fall into the excavated area. The Authority used long tension bolts so placed as to compress the rock around the tunnel for thicknesses in the order of 3 metres. In other words, broken or jointed rock surrounding the tunnel was converted into a self-supporting arch structure. One advantage of this process was that rock bolting could proceed simultaneously with tunnel-face drilling, avoiding time-consuming installation of steel supports which inevitably disrupts other tunnelling work. Tim Besley has this to say on its merits:

"I think that the Snowy can legitimately claim that it took the science of rock mechanics a quantum leap forward. We looked at the concept of using bolts as a design method to reinforce shattered rock. Nobody had done that before. Experiments were done under the guidance of Associate Commissioner Lang in the Scientific Services laboratories. These were really all directed towards understanding the pressures in rocks, the stresses and so on, and finding a way to use the bolts, not just as pins for individual lumps of rock but as a means of reinforcing around a tunnel for example. It emerged that it was quite feasible and much less costly in two respects: firstly, they were not as costly as a great steel support and, secondly, if instead of rock bolts you were to use steel supports and concrete lining in areas of broken rock, you would have to dig a tunnel considerably wider in order to finish up with the specified diameter."[74]

Rock bolts were used extensively in the Snowy tunnels and underground power stations. In some places a calculated risk was taken in not lining sections of broken rock, but despite the fact that much of the Snowy tunnel system was left unlined, very few falls have occurred. The decision on whether a weak section of excavated rock should be lined or bolted was made by the Authority's Tunnel Lining Committee, and their decision, at least on one occasion, seems to have caused concern to one of the Authority's engineering consultants. The Authority had engaged a number of eminent engineering consultants for advice on special problems. One of these men was Raymond Hill from Los Angeles. Engineer Ross McIntyre:

"In the Murrumbidgee–Eucumbene tunnel we had some bad areas to go through because there was a cadastral fault. This is a major fault which runs from Canberra through to Bright in Victoria, and it just so happened that the Murrumbidgee–Eucumbene tunnel skirted that fault near the Murrumbidgee end. We were therefore in and out of problems and at one stage we were going to divert the tunnel around it but we worked our way out of trouble. I travelled through the tunnel with Mr Hill and very proudly said, 'Well Mr Hill, don't you think it's pretty good? We have only got 17 percent lining in this tunnel.' He turned to me and he said, 'Laddie, if this was my tunnel, I would have it 100 percent lined.' That was what he thought of our innovations and the risk-taking we engaged in. There hasn't been any problems in that tunnel, but those were his feelings." [63]

It is not surprising that a consultant would take a conservative approach to the Authority's innovative use of rock bolts. What is surprising is that the Authority was prepared to use innovative methods as often as it did. Organisations spending public money tend to be very conservative, since criticism of errors in judgement are normally feared more than are increases in the cost of carrying out the work. Merigan referred to this fear of criticism faced by public bodies:

"This is the greatest handicap to real enterprise in government organisation. There should be no penalty for a single error of judgement if that decision was made after a full appraisal of all of the relevant facts. Occasionally there arises an individual who is confident of his ability to meet and overcome criticism when it arises and who is prepared to exercise his judgement as to what is best for the organisation in the particular circumstances. If that individual is the head of an establishment, this same acceptance of responsibility quickly manifests itself throughout the organisation. Inevitably mistakes are made, but the cost of these mistakes is nothing compared with the cost of suppression of initiative which arises from fear of criticism." [83]

Initiative and enthusiasm were the hallmarks of the Snowy people from the beginning. In the late 1950s the enthusiasm was fuelled by increasing confidence and pride in the Authority's growing list of achievements: the Eucumbene dam was completed in May 1958, two years ahead of schedule; by 1959 the record-breaking tunnelling teams had completed the Eucumbene–Tumut tunnel four months ahead of schedule; and Tumut 1 power station was in full operation in September 1959, six months ahead of schedule.

SOURCES OF QUOTATIONS

Unless otherwise stated, the interviews listed below were taped by the author.

1 Interview taped in 1974 with Rt Hon. Sir William McKell GCMG, QC, Hon. LLD Syd., Governor-General of Australia 1947-53, Premier and Treasurer of NSW 1941-47

2 Interviews taped in 1974-76 with Sir William Hudson KBE, FRS, BSc (Eng.), MICE, Commissioner of the Snowy Mountains Authority 1949-67.

3 First draft of transcribed interview with Sir William Hudson for the Archives of the National Library by Mel Pratt in February 1971.

4 Australian Broadcasting Commission interview with Sir William Hudson by Bob Logan on the program 'Conversations with Sir William Hudson' in 'The Countryman's Session' on 2 February 1969.

5 Sound track of ABC program, 'The Commissioner', in the television series 'A Big Country' July 1974.

6 Speech on 'Tourist development arising from the Snowy Mountains Scheme' delivered by Sir William Hudson to an Australian National Travel Association convention in Melbourne in 1960.

7 Letter from Sir William Hudson to the author in 1971.

8 ABC broadcast interview with Sir William Hudson for 'Profile' series (date unknown).

9 Reminiscences taped and sent to the author in 1974 by W.M. Shellshear ASTC (Mech.Eng.), FIE Aust., engineer with the SMA 1949-73.

10 Interview taped in 1974 with G.C. Shain BE, FIEE, engineer with the SMA 1952-72, transferred to SMEC.

11 Interview taped in 1974 with N.L. Hain BEM, Cooma retailer (owner and manager of Hain & Co.), alderman of Cooma Municipal Council 1947-71, Mayor of Cooma 1954-60.

12 Interview taped in 1974 with C.R. Ampt BEE, electrical engineer with the SMA 1950-80

13 Letter and interview taped in 1974 with P.R.K. Seidel MIS Aust., surveyor with the SMA 1951-54.

14 Interview taped in 1974 with A.P.H Werner Dip.Ing. (Bonn), surveyor with the SMA 1951-60.

15 Interview taped in 1974 with A.A. Dunn, administrative officer with the SMA 1951-72.

16 Interview taped in 1975 with F.T. Rollings, driver, works foreman, certified coxswain and certified diver with the SMA 1949-70.

17 Interview taped in 1973 with J.K. Wilson MIMH, labourer, driver, transport supervisor, Regional Transport Officer and Transport Officer with the SMA 1949-72.

18 Interview taped in 1973 with Mrs G.M. Croatto (née Gwen MacGregor) secretary to Commissioner Hudson 1949-65.

19 Interview taped in 1984 with P. Rogers-Irvine, administrative officer with the SMA since 1957 and still employed at time of interview.

20 The Ninth William Queale Memorial Lecture 'Management on the Snowy Mountains Scheme', delivered by Sir William Hudson to the Australian Institute of Management, Adelaide Division in the Bonython Hall, Adelaide 18 October 1962.

21 *Catchment Protection in the Snowy Mountains* by E.S. Clayton, published by the SMA, January 1967. Clayton became consultant to the SMA after his retirement as Commissioner of Soil Conservation Service of NSW.

22 Letter to the author in 1985 from Mrs H. Psenner, resident of Jindabyne construction township and Cooma North 1951-69

23 Interview taped in 1984 with A.W. Joyce, Senior Amenities Officer with SMA 1950-71.

24 Interview taped in 1972 with I. Kobal, chainman and carpenter with the SMA 1954-58.

25 Interview taped in 1974 with T.E. Lewis BCE, FIE Aust., civil engineer with the SMA 1950-71. Transferred to SMEC

26 Interview taped in 1973 with F.R. Gibbs, model-maker with the SMA 1951-67.

27 Interview taped in 1973 with H. Berents LRCP, MRCS, medical officer with the SMA 1952-67.

28 Interview taped in 1975 with H.P.I. Knauer Dipl.Ing.(Dresden), surveyor with the SMA 1951-54.

29 Reminiscences taped and sent to the author in 1971 by V.S. Gadsby ARPS, photographer on loan to the SMA from Department of Information 1949, employed by the SMA 1950-67.

30 Interview taped in 1974 with C. Aggio, chainman with the SMA 1951-59.

31 Interview taped in 1973 with K.E. Timmel D.Phil., FIE Aust., employed by the SMA 1951-73.

32 Written comments and interview taped in 1973 and 1984 with E.G. Warrell MCE, FIE Aust., civil engineer with SMA 1951-69, Associate Commissioner 1965-69.

33 Interview taped in 1973 with W. Wasserman, Dipl.Ing.(Bonn), Grad.Ing. (Frankfurt), MIS Aust., surveyor with the SMA 1951-68.

34 Interview taped in 1973 with Mrs A.P.H.Werner, photographer with the SMA 1951-53, resident of Cooma North and Tantangara 1951-60.

35 Interview taped in 1980 with G. Fekete BE (Berlin and Budapest), FIEA, FIStruct.E, engineer with the SMA 1951-66.

36 Interview taped in 1978 with C.J. Benneworth, Regional Stores Officer, OIC Stores, and Comptroller of Stores with the SMA 1952-74. Advisor to SMEC 1975.

37 Interview taped in 1972 with J.C. Purcell ASTC, AMIE, civil engineer with the SMA 1957-59.

38 Interview taped in 1977 with Dr Muriel McPhillips, resident of Adaminaby area and part-time medical officer with the SMA.

39 Interview taped in 1974 with Mrs Les Neely (née M.G. McQuade), also written reminiscences prepared by Mrs Neely on her retirement. Mrs Neely was a clerk and administrative officer with the SMA 1953-69.

40 Interview taped in 1972 with T.A. Bowey J.P., an administrative officer with the SMA 1950-74.

41 Interview taped in 1974 with S.S. Harrison MNZIS, AMNZIE, AMICE, MICE, MIE Aust., civil engineer with the SMA 1951-61.

42 Interview taped in 1977 with Mrs R.H. Blake, resident of Island Bend and Cabramurra 1951-56.

43 Interview taped in 1977 with R.P.A. Blake, son of Mrs R.H. Blake (see 42).

44 Interview taped in 1973 with Mrs K.E. Timmel, (née J.K.Pratt), secretary with the SMA 1952-58.

45 Interview taped in 1975 with J. Madarasi, welder with the SMA (dates unknown).

46 Interview taped in 1977 with W.F. Spradley, employed by Arnolds Engineering, Sydney (dates unknown).

47 Reminiscences written in 1979 by H.E. Roots, FRSA, Public Relations Officer, Cooma, with the SMA 1952-54.

48 Interview taped in 1973 with H.L. Malcolm, ACS, producer, cinematographer with the SMA 1953-74.

49 Conducting Officers' Manual, Snowy Mountains Hydro-electric Authority, March 1965.

50 Interview taped in 1974 with G.E. Ramsay, Public Relations Officer with SMA 1950-64.

51 Interview taped in 1985 with Mrs J. Klima, Draughting Assistant and Administrative Officer with the SMA 1953-55 and 1960-70. Transferred to SMEC.

52 Interview taped in 1980 with Mrs G. Fekete, resident of Cooma North 1951-66.

53 Letter and interview taped in 1974 with K.W. Montague MIE, Aust., engineer with the SMA since 1953 and still employed by the Authority in 1985.

54 Interview taped in 1985 with Mrs A. Knowles, Finance Clerk with the SMA 1951-69.

55 Interview taped in 1972 with Mrs J.K. Wilson, resident of old Adaminaby, Cabramurra, Cooma North, Talbingo and Khancoban, 1949-72.

56 Interview taped in 1975 with D.C.B. Maclurcan OBE, KCSG,ARIBA, LFRAIA, FIES Aust., architectural consultant to the SMA and member of the Authority's Committee on Aesthetics of Major Engineering Structures 1957-71.

57 Reminiscences taped and sent to the author in 1974 by C.G. Parris, BEE (Melb), MIEE, MIE Aust., engineer with the SMA 1950-76.

58 Interview taped in 1974 with Mrs J.R. Dudas, resident of Cabramurra, Thiess Village, Cooma, Island Bend and Talbingo 1957-72.

59 Interview taped in 1986 with A. Duczynski, field hydrographer, Regional Hydrographic Officer, Officer-in-charge Records Section with the SMA 1952-72. Transferred to SMEC.

60 *Corryong and the 'Man from Snowy River' District* by the Hon.T.W. Mitchell, CMG. Printed and published by Wilkinson Printers, Albury, NSW 1981.

61 Interview taped in 1974 with D.R. Mullins, clerk in SMA Sydney office 1956-74.

62 Introduction to *Men of the Snowy Mountains* by Mona Ravenscroft, Rigby Limited, Adelaide, 1962, p.15.

63 Interviews taped in 1973 and 1984 with A.R. McIntyre BE, MIE Aust., engineer with the SMA 1950-66.

64 Reminiscences written in 1972 by Mrs I.R. Griffiths, resident of Kennys Knob, Cabramurra and Cooma 1957-84

65 *Discovering Monaro—A Study of Man's Impact on his Environment* by W.K. Hancock, Cambridge University Press, 1972.

66 Interview taped in 1976 with Mrs E.M. Julien MA, Dip Ed, MACE, resident of Cooma 1951-59.

67 Interview taped in 1974 with W.G.R. Gilfillan BCE Melb., MIE Aust., JP, engineer with the SMA 1951-71.

68 *Sun-Herald* 24 April 1955.

69 *Snowy Scheme Management and Administration* by D.J. Hardman MEc (Syd.), B.Com (Qld), AAUQ, AASA (Senior), ACIS. Published by West Publishing Corporation Pty Ltd, 1970, p. 165.

70 Interview taped in 1972 with Mrs J.C. Purcell, typist with the SMA and resident of Cabramurra 1957-59.

71 *The Journal of The Institution of Engineers, Australia*, March 1969, Vol.41, 'Two Decades of Engineering—The Snowy Mountains Scheme' by H.E. Dann, CBE, B.Mech.E, FIE, Aust. Paper no. 2691.

72 Interview taped in 1974 with P.M.Macpherson BCE (Melb.), engineer with the SMA 1954-71. Transferred to SMEC.

73 Letters and interview taped in 1984 with E.L. ('Tony') Merigan CBE, BEE, AMIE (Aust.), Associate Commissioner with the SMA 1950-65.

74 Interview taped in 1984 with M.A. ('Tim') Besley BE (Civil) NZ, BLeg.S (Macquarie University), FIE Aust., engineer with the SMA 1950-67.

75 Interview taped in 1985 with Mrs J.C.S. Zilverschoon, Female Assistant with the SMA in 1951, resident of Cooma North from 1951 until time of interview.

76 Interview taped in 1984 with Mrs A.R. McIntyre, resident of Cabramurra, Tantangara, Khancoban and Cooma North 1951-66.

77 Snowy Mountains Authority Magazine, *Snowy News* issue no. 106, November 1970.

78 Interview taped in 1984 with Mrs E.G. Warrell, resident of Cooma North 1952-69.

79 Interview taped in 1984 with Mrs S. Jones, typist with the SMA and resident of Cooma and Geehi 1956-61.

80 Interview taped in 1984 with Lady Hudson OBE, wife of SMA Commissioner, Sir William Hudson, resident of Cooma North 1951-67.

81 Interview taped in 1984 with F.W. Rodwell, labourer, leading hand, ganger, plant operator, heavy transport driver, patrol officer, security officer with the SMA from 1955 and still employed at time of interview.

82 Biographical notes on Sir William Hudson prepared by colleagues after his death in 1978. The notes were prepared to assist Sir Angus Paton FRS in the preparation of Hudson's biographical memoir for inclusion in *Biographical Memoirs of Fellows of the Royal Society*, Volume 25, November 1979.

83 'Management Problems in Great Constructional Projects—Top Management in the Snowy Mountains Hydro-electric Authority', a paper delivered to Twelfth International Congress of Scientific Management 1960 by E.L. Merigan.

84 *Power from Water*, information pamphlet published by the Snowy Mountains Hydro-electric Authority in 1984.

85 'Snowy News' appeared every Friday in *the Cooma-Monaro Express* and was written by members of the SMA's Public Relations staff.

86 Interview taped in 1984 with J.N. Yabsley, Inspector of Schools in the Snowy Mountains area 1959-61.

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APPENDIX E – APPLICATION TO NSW HERITAGE REGISTER, 2006

APPENDIX E – APPLICATION TO NSW HERITAGE REGISTER, 2006

ENGINEERS AUSTRALIA
Sydney Division

Engineers Australia
Monaro Country Group

30 October 2006

NSW Heritage Officer
Locked Bag 5020
PARRAMATTA NSW 2124

Dear Sir

LISTING ON STATE HERITAGE REGISTER
ROCK BOLTING DEVELOMENT SITE – LAMBIE GORGE COOMA

The Monaro Group of Engineers Australia is submitting the attached application for listing on the NSW State Heritage Register

In our opinion, the item is worthy of national recognition The site represents a window into our pioneering engineering practice of rock bolting for the permanent reinforcement of underground tunnels and caverns in hard rock In the process of developing the rock bolting practice the engineering discipline of rock mechanics became a specialist practice. Both the rock bolting practice and the study of rock mechanics was taken up internationally by being shared through universities, learned societies and via the tunneling achievements by major international construction contractors engaged with the Snowy Mountains Scheme

Many personnel, all as employees of Snowy Mountains Hydro-Electric Authority in both engineering and scientific fields of expertise, contributed successfully to the full development of engineering for rock bolting. This work took place in the late 1950s and early 1960s and it was a first for Australia and the world

In response to preliminary data on the site supplied by our Mr W B Mills to Engineers Australia, Sydney Engineering Heritage Committee, he was advised in March 2004 that they "agreed that the Rock Bolting Development Site is unique and of great importance in the history of engineering" We will also be applying to seek recognition under the Australian Historic Engineering Plaquing Program established under Engineers Australia

If you require more information relating to the application please doe not hesitate to contact the Group's Sub-Committee Chair Mr Wally Mills on 02 6452 7321(h) or the Group's Chair Mr David Byrne on 02 6450 1750(w)

Yours faithfully

Walter B Mills, BE	Alan Hall, BE (Hons) MEng SC	David Byrne, BE (Civil)
MIEAust CPEng NPER	**MIEAust CPEng**	**MIEAust CPEng NPER**

Rock Bolting Heritage Sub-Committee, Monaro Group, Sydney Division, Engineers Australia

NSW Heritage Data Form

NSW Heritage Office

ITEM DETAILS						
Name of Item	ROCK BOLTING DEVELOPMENT SITE, LAMBIE GORGE, COOMA					
Other Name/s Former Name/s	COOMA BACK CREEK, SCIENTIFIC SERVICES DIVISION, SMHEA					
Item type (if known)	LANDSCAPE / BUILT					
Item group (if known)						
Item category (if known)						
Area, Group, or Collection Name	LAMBIE GORGE					
Street number	N/A					
Street name	SHARP STREET					
Suburb/town	COOMA				**Postcode**	2630
Local Government Area	COOMA MONARO SHIRE COUNCIL					
Property description	LOT 3 OF DP 704165 SHEET 1 REGISTERED 30 OCTOBER 1984 AS ATTACHED					
Location - Lat/long	**Latitude**	36° 14'		**Longitude**	140° 07"	
Location - AMG (if no street address)	**Zone**		**MIN Easting** 690 000	**MAX Easting** 690 175	**MIN Northing** 5986 750	**MAX Northing** 5987 050
Owner	STATE GOVERNMENT					
Current use	CROWN LAND DEDICATED FOR ENVIRONMENTAL PROTECTION					
Former Use	1. ABORIGINAL CAMPING AREA 2. DAIRY PADDOCK 3. SCIENTIFIC EXPERIMENTS					
Statement of significance	From the mid 1950s through to the early 1960s the Snowy Mountains Hydro-Electric Authority (SMHEA) was the first in the world to develop the technology of grouted rock bolting integrated to the strength of the materials found in underground construction. This site was use to start the development of this engineering practice. Rock bolting was used as a permanent mechanism for the stabilising and reinforcement of the exposed hard-rock class of material in underground excavations. The technique was shared internationally and very rapidly was adopted worldwide. Rock bolting continues to be in use as standard practice for safe and permanent reinforcement of exposed excavations.					
Level of Significance	Australian, National and State ☒			Local ☒		

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DESCRIPTION						
Designer	REFER TO ATTACHMENT 1					
Builder/ maker	SNOWY MOUNTAINS HYDRO-ELECTRIC AUTHORITY PERSONNEL					
Physical Description	Natural rock into which holes have been drilled. Bolts of various designs may be seen projecting from some of these holes. There are two main areas where the rock bolting experimental tests were conducted. A succession of tests were conducted in the area at the downstream end of the gorge. Attached is a copy of the descriptive and diagrammatic signage of the rock bolting site. (2 sheets)					
Physical condition and Archaeological potential	The holes and bolts are in excellent condition as they have not been disturbed. The broken rock and bolts from previous experiments are still in place.					
Construction years	**Start year**	1956	**Finish year**	1962	**Circa**	☐
Modifications and dates	A succession of test faces are evident by the blasted fallen rock in front of the main test area. This was undertaken within the span of the test site usage.					
Further comments	The aim of the rock bolt was to have the anchor hold the full elastic tensile strength of the bolt shaft. Pull-out tests were conducted here to obtain data that would show the anchorage strength compared to the bolt (shaft) strength. A dozen or so rock bolts at the site were used for grouting strength tests. Many other steps were taken in the scientific laboratories of SMHEA to make an integrated, fully developed rock bolt reinforcement system that remained as a permanent structure, protected from corrosion.					

HISTORY	
Historical notes	**Introduction** From the mid 1950s through to the early 1960s the Snowy Mountains Hydro-Electric Authority (SMHEA) was the first in the world to develop the technology of grouted rock bolting integrated to the strength of the materials found in underground construction. This site was used to start the development of this engineering practice. Rock bolting was used as a permanent mechanism for the stabilising and reinforcement of the exposed hard-rock class of material in underground excavations. The technique was shared internationally and very rapidly was adopted worldwide. Rock bolting continues to be in use as standard practice for safe and permanent reinforcement of exposed excavations. The Cooma Rock Bolting Development Site represents the first field location for this integrated development of rock bolting technology in rock mechanics engineering. The early pre-construction site tests for in situ experimental work was in a rocky gorge in Cooma, adjacent to the Authority's Scientific Services materials testing laboratory. This experimental site is still as it was left some 45 years ago and is accessible to the general public. It shows the remnants of a succession of experiments, of a variety of bolt types, where it was the aim to prove a rock-bolt anchorage that was as strong as the bolt itself. The experimental site was part of the overall work of fully developing the rock-bolting technology. Many people were engaged within several engineering laboratories of the SMHEA, the civil design office and at the underground construction sites themselves for the massive Snowy Mountains Hydro-Electric Scheme. In addition, efficient installation techniques were devised so as to maximise the effectiveness of rock bolting for all its benefits to a project. The work in the gorge on successive occasions led to the approval for the commercial supply for rock bolting components under a series of underground construction contracts of the Scheme. Permanency of the rock bolting design was crucial to its full development and acceptance. This came from sealing the whole bolt system and by transferring the tensile force from each bolt positioned in a pattern of rock bolts across the total span into a lasting compression and locking force across the exposed rock face. This aspect of the development was proven in the laboratories and refined under contract conditions at the construction sites. The Cooma Rock Bolting Development Site represents a suitable location for recognising the total engineering development of rock-bolting and the development of the engineering discipline of rock mechanics as it is known today. It was a SMHEA team effort lead by engineering management that delivered very significant achievements in tunnelling speeds regularly setting new world records, very large savings in construction costs, improved construction worker safety and generated enthusiasm and pride in all the project work for the Authority.

Rock Bolting – the detailed description and justification

Hard rock type rock bolting involves drilling a hole about 30mm dia into sound rock at the excavated face, commonly between 1.50m and 6.00m long depending on conditions and rock structure, and inserting a device incorporating a steel rod with an expansion unit at the embedded end, a threaded nut at the exposed end, then fully de-aerating by displacement with grout while the bolt is under predetermined tension. Thus it creates zones of compression in the surrounding rock and along the length of each bolt together with a transverse force component as well. The expanded unit at the far end grips against the sound rock of the drilled hole, thus forming an 'anchor' for the rod, which when tensioned against a plate at the surface, the compressive and transverse forces lock the layer of rock against further movement, holding it in its as-found place. But it also adds strength by providing a pre-stressed membrane (with the profile of the excavation) in the excavated rock face to effectively neutralise the internal rock forces. The use of non-shrinking grout then enables the bolt components to transfer load to the adjacent rock over its whole length, as well as provide an inhibiting environment against corrosion.

In most instances, rock bolting can replace the need for surface steel supports and the accompanying over-excavation to accommodate them and can avoid the need for separate concrete support of underground excavations.

It has been estimated that rock bolting reduced the steel required for support, to one eighth of that required using conventional methods. It also saved the cost of over excavation (and removal of the additional excavated rock), to accommodate supports and/or lining. Contractual pricing at the time resulted in a 45% increase in cost for fully concrete lined tunnels, where the rock face had light steel external supports instead of rock bolts. Much time and labour were saved in just these excavation benefits, and it was also an enhancement to tunnelling safety. This amounted to an additional time saver in that the rock bolts were installed simultaneously with the face drilling and face exposure.

Location of the Rock Bolting Development Site

The lot of land in which the Rock Bolting Development Site falls is Crown Land administered by the NSW Department of Lands. It is of approximately 1.042 hectares, being Lot 3 of Deposited Plan 704165, and was registered on 30 October 1984. It was later gazetted by the NSW Parliament for environmental protection as a public place.

The Rock Bolting Development Site itself forms only a small portion of the total area of the Lot covering the right bank of what is generally known as Lambie Gorge, through which Cooma Back Creek flows. It is accessed by a Public Reserve pathway along the right bank of the stream, via the Cooma Bowling Club rinks verge, and

	through the Cooma Agricultural and Pastoral Society Showgrounds to the Park commemorating the "Southern Cloud" airliner adjacent to the Snowy Mountains Highway in central Cooma. Like the whole of the land of Australia, Lambie Gorge does have evidence of the occupation by the Aboriginal people up until the time of European settlement in the 1830s. The Aboriginal people's descendants of Ngarigo Nation today, through their Elders, want to use this Lot to share their own heritage. The artifacts found within the Lot indicate that it was frequented by all family members for camping. There are no monuments, no artworks, nor songs associated with the place. As a result of an archeological inspection in 2002 by the NSW National Parks and Wildlife Service, it was concluded also that there were no confirmed grinding grooves in the watercourse. The recognition of the Rock Bolting Development Site as an engineering heritage item has been accepted in a true partnership with the Ngarigo Nation people as an expression of reconciliation on this land. It is evidenced by the tourist brochure produced in 2005, "Lambie Gorge Walking Track". This was a project of the Cooma Reconciliation Committee. Refer to the attached two sheets. The Rock Bolting Development Site on Cooma Back Creek in Lambiie Gorge was deliberately chosen for geological reasons. It was because of the close similarity in mineralogical composition to the Cooma gneiss found there to the granite found to exist in the known construction sites in the Snowy Mountains. These construction sites were for two underground hydro-electric power stations, Tumut 1 and 2, and their associated tunnels adjacent to a new construction township of Cabramurra in what is known still as the Upper Tumut Region. Reference is made to this Development Site decision in the last paragraph of Reference 1. The other factor giving rise to the usefulness of the Rock Bolting Development Site was that it could be regarded as the curtilage to the actual Engineering Laboratories of Scientific Services Division of SMHEA. These laboratories were where the testing personnel worked and with their testing apparatus, both fixed and portable. What's more, all this land was then under the ownership of SMHEA and had been in use for six years in connection with other experimental work associated with the laboratories. At this point in time, in the preparation of this document, the original SMHEA building for Engineering Materials and the storage buildings still stand - but possibly for not much longer. The photograph attached, shows the relationship of the Site (near the rock abutment on right) to the laboratory seen in the centre background. In the testing activity years, a foot bridge at the height of the flood plain allowed for the crossing of Cooma Back Creek to the Rock Bolting Development Site from the Laboratories.

	1. Attachment 1 – SMHEA memorandum 27 August 1956 from D G Moye, Head of Engineering, Geology Branch, identifying the site for rock bolting experiments (2 pages). 2. Attachment 2 – SMHEA Engineering Construction Materials Report No. SM 1309. May 1962 – Field Pull out Tests on Strengthened Bayliss – Jones – Bayliss quick set rock bolt anchorages R T Brodie & A D Hosking (Attention paragraph 3.2) (6 pages). 3. Attachment 3 - Journal I E. Aust. Vol 35, No 7-8, July-August 1963 pg 129-150 – Grouted Rock Bolts for Permanent Reinforcement of Major Underground Works E B Pender, A D Hosking, R H Mattner (23 pages). 4. Attachment 4 – Australian Academy of Sciences. Academy Symposium 1999 Rock Mechanics and the Snowy Scheme E T Brown (5 pages summary)

THEMES	
National historical theme	Engineering innovation and learning, gifted to the world : rockbolting and rock mechanics
State historical theme	Engineering innovation and learning, gifted to the world : rockbolting and rock mechanics

APPLICATION OF CRITERIA	
Historical significance SHR criteria (a)	The work undertaken at this site is the genesis of the applied science of rock mechanics and its further international development.
Historical association significance SHR criteria (b)	The site has a special association with SMHEA and through them by technical presentations and by the major tunnelling contractors to an international engineering fraternity. It inspired the whole organisation to achieve excellence in the whole development of the Scheme.
Aesthetic significance SHR criteria (c)	A high degree of creative and lateral thinking by the personnel involved led to a quantum leap in the development in the science, savings in the Scheme costs, improvement in safety, the speed of tunnelling.
Social significance SHR criteria (d)	Rock bolting is regarded as the most significant engineering development made on the Snowy Scheme. There were fewer tunnelling accidents from post excavation rock falls, giving rise to close-knit team work by a shift crew working months on end for approximately a two year span.
Technical/Research significance SHR criteria (e)	The site gives a window to appreciate what is concealed of the successful engineering of more than 100 km of tunnels and many huge underground caverns. Ample inspiration is available to fully establish the precedence of the SMHEA work and its impact in the engineering fraternity worldwide. The pre-SMHEA work on roof anchors from which the rock bolting development came is documented, in part, in the bibliography of Attachment 3. It is also available to a large extent in Box 30 of D G Moye's papers, ref Doc. 9.1
Rarity SHR criteria (f)	This was the first pioneering site where such activity was undertaken and there is no other similar site anywhere in the world.
Representativeness SHR criteria (g)	The rock in Lambie Gorge is the closest representation of the rock types encountered on the Scheme sites and were fortunately located adjacent the SMHEA laboratory site. Rock bolts in service are not available to view by the general public, but their story of Australian creativity needs to be told from this site.
Integrity	The site retains many of the bolts and drilled holes that were the original field tests.

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HERITAGE LISTINGS

Heritage listing/s	The site is included in the draft heritage list developed as part of the draft Cooma-Monaro Shire Council Local Environment Plan

INFORMATION SOURCES

Include conservation and/or management plans and other heritage studies.

Type	Author/Client	Title	Year	Repository
	Engineers Australia Monaro Group	Lambie Gorge Rock Bolting Heritage Site, Cooma, NSW Management Plan Outline	2006	Monaro Group, Cooma.
	Daniel George Moye	Personal Paper MS5861		National Library of Australia
	SMH&A	Various		National Archives of Australia
	Professor TJD Leech	Personal Paper MS4837		National Library of Australia

RECOMMENDATIONS

Recommendations	The site, Lambie Gorge Rock Bolting Heritage Site, Cooma, NSW, be listed on the NSW State Heritage Register.

SOURCE OF THIS INFORMATION

Name of study or report		**Year of study or report**	
Item number in study or report	Attachment 5 – Personnel credited with substantially contributing to the Engineering of the Rock Bolting Technology and the engineering discipline of rock mechanics 2006. Attachment 6 – Index of Reference Papers for Heritage Recognition, 2006.		
Author of study or report	Walter B Mills		
Inspected by	Alan Hall and David Byrne		
NSW Heritage Manual guidelines used?		Yes ☒	No ☐
This form completed by	Walter B Mills, Engineers Australia, Monaro Group Alan Hall, (Deputy Chair), Engineers Australia, Monaro Group David Byrne, (Chair) Engineers Australia, Monaro Group	**Date**	

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IMAGES - 1 per page

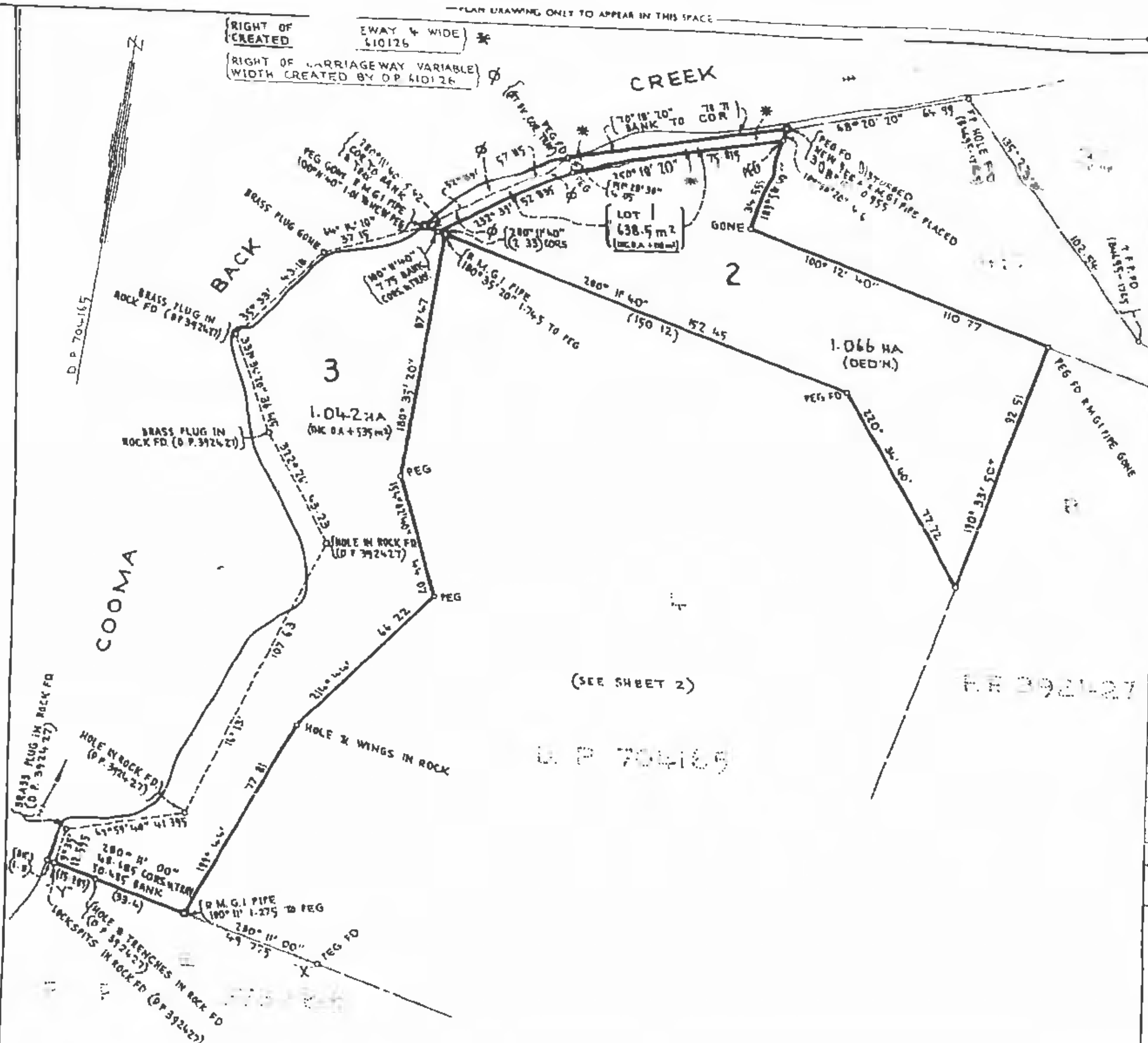
Please supply images of each elevation, the interior and the setting.

Image caption	Downstream end Lambie Gorge, just upstream of the last pool looking downstream (north).				
Image year	2006	**Image by**	W B Mills	**Image copyright holder**	W B Mills

Lambie Gorge

Main Rock bolting experimental site - drill holes, rock bolt remnants and information boards
With viewing area in foreground
Rock from the rock face is forward in the foreground (not in view)

NOTES



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C.A.	
Title System	TORRENS
Purpose	ACQUISITION (NOT CURRENT PLAN AT REGN - SEE S 7 (1A) L.G. ACT)
Ref Map	Q0982 - 15.14
Last Plan	D.P. 610126
PLAN OF SUBDIVISION OF LOTS 21 AND 22, D.P. 610126	
REDUCTION RATIO 1: 1000	LENGTHS ARE IN METRES
SHIRE	COOMA - MONARO
LAND DISTRICT	COOMA
LOCALITY	SUBURBAN LANDS, TOWN COOMA
PARISH	COOMA
COUNTY	BERESFORD

THIS IS SHEET 1 OF MY PLAN IN 2 SHEETS (DELETE IF INAPPLICABLE)

I, GILBERT ANTHONY FLOOD of P.O. BOX 223, GOULBURN, 2580 ... AS REGARDS LOTS 1 & 3 (LOTS 2 & 4 COMPILED FROM D.P.'S 392427 AND 610126) ... 24 [illegible] 1984

Signature: [signature]

AZIMUTH TAKEN FROM "XY" (D.P. 392427)

FIELD BOOK [L.B. 1986-2 GOULBURN] PAGE 7 TO 53

PAPER NO. 69.81 R 42 GOULBURN

PLAN APPROVED [signature] 24TH APRIL [illegible]

MPD

WARNING CREASING OR FOLDING WILL LEAD TO REJECTION

SURVEYORS REFERENCE 4884/6

I, Bruce Richard Davies, Under Secretary for Lands and Registrar General for New South Wales, certify that this negative is a photograph made as a permanent record of a document in my custody this day.

30th October, 1984

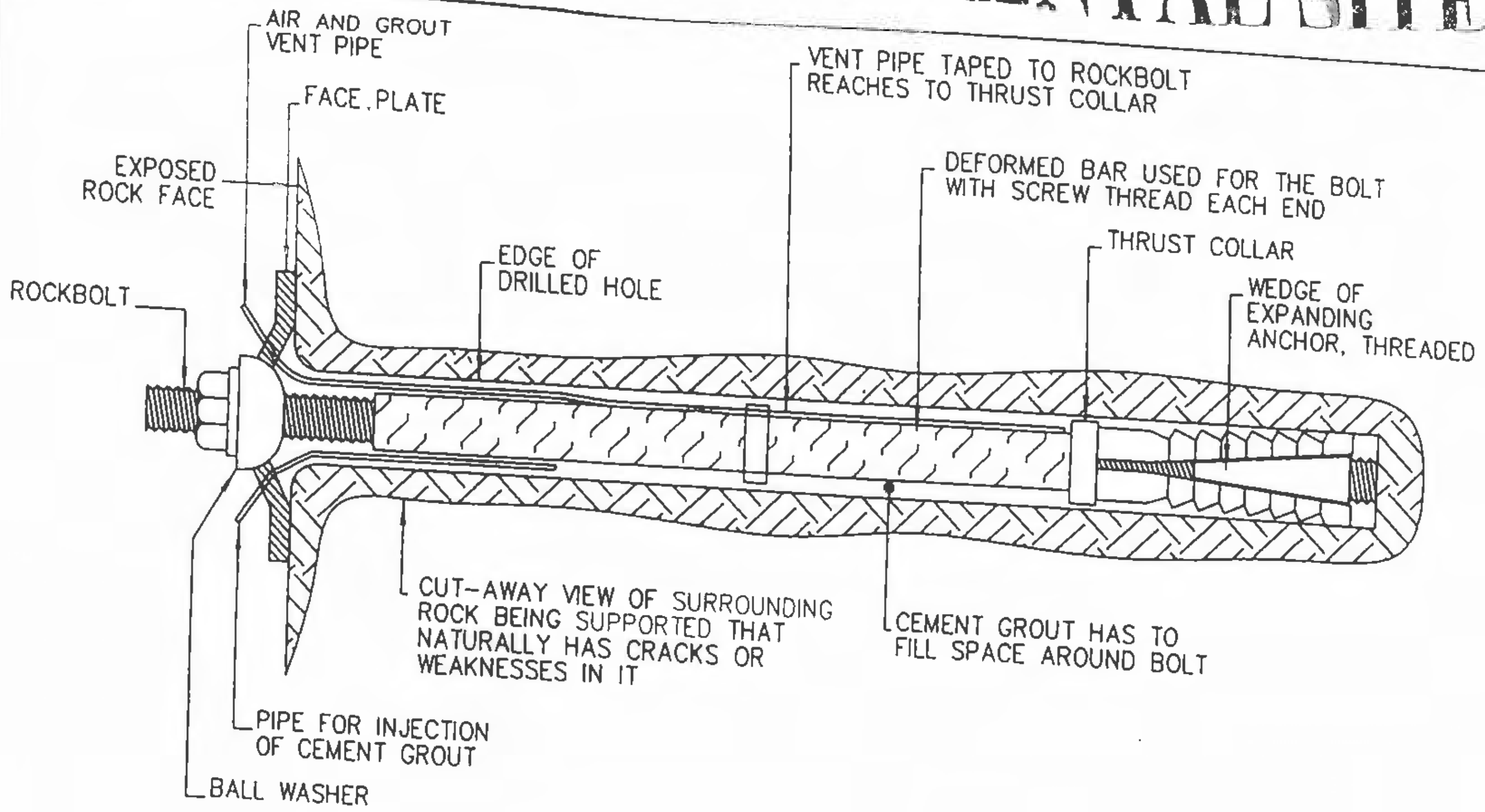
ROCK BOLT EXPERIMENTAL SITE

Lambie Gorge is the site where Snowy Mountains Hydro-Electric Authority tested unique designs of various rock bolts during the 1950s. The rock bolts developed were used to stabilise the exposed rock in underground excavations. It was important to develop an anchorage that was as strong as the bolt itself.

In actual use, the rock bolt (up to 4m long) is inserted quickly into a drilled hole, anchored and tensioned against a surface plate to compress the surrounding rock. When rock bolts are in a pattern across an excavation, the clamping action creates its own arch support. For permanency, rock bolt holes are then immediately injected with grout to bond the rock bolt and rock as one. This also stops the possibility of corrosion of the rock bolt.

At this site, 'pull-out' tests guided the rock bolt development, resulting in safe tunnelling for the Snowy Mountains Scheme. The design and application soon became a world-wide engineering practice.

ROCK BOLT EXPERIMENTAL SITE



START WITH HOLE DRILLED STRAIGHT INTO EXPOSED ROCK
ROCKBOLT OVERALL LENGTH UP TO 4 METRES

TYPICAL GROUTED ROCKBOLT IN-PLACE
FOR SELF SUPPORT OF UNDERGROUND CAVERNS & TUNNELS IN HARD ROCK

W B Mills, COOMA June 30, 2005

Water over stone

Lambie Gorge is a site centred on Cooma Back Creek a small stream which in heavy rain can become what some specialists would call an active excavator – or raging torrent. The Gorge owes its origins to a number of factors. The stream is superimposed on an ancient rock mass known as Cooma Granodiorite. This rock mass, or small pluton, covers 30 square kilometres.

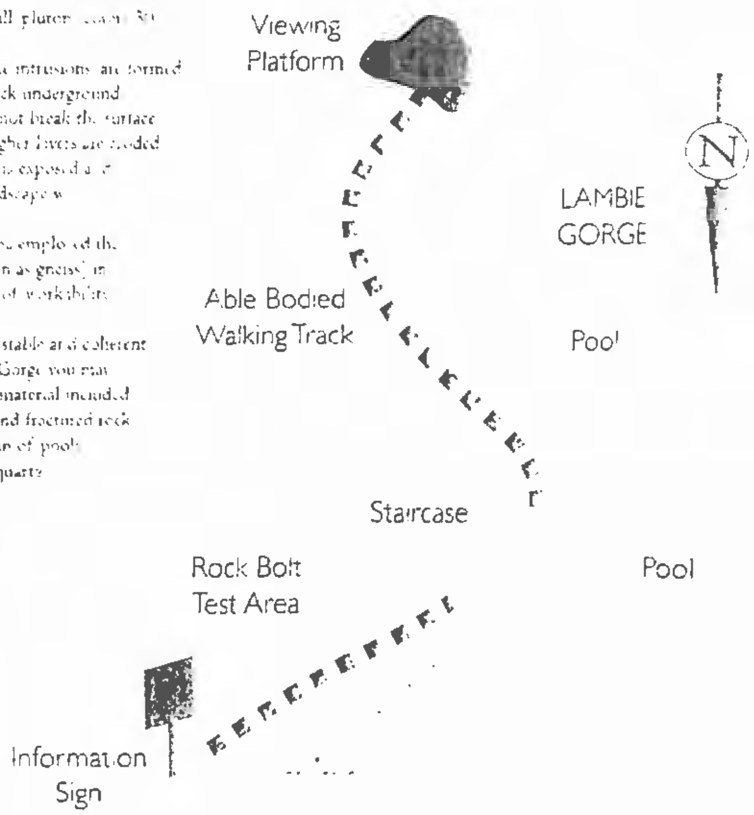
Plutons or small granite intrusions are formed by activity of molten rock underground. Initially the pluton does not break the surface but over time when the higher layers are eroded away the underground mass is exposed and becomes the surface of the landscape we can see today.

Many of the buildings in early Cooma employed the more massive form of this rock (known as gneiss) in their construction due to its relative ease of workability for stone masonry.

Some of the rock takes the massive or more stable and coherent form but in some plutonic rock found in the Gorge you may notice linear patterns with odd pieces of other material included. The Back Creek which cuts through the jointed and fractured rock has been able to cut out a narrow gorge with a chain of pools which contains gravels from various sources: basalts, quartz, quartzites and other rock types.

Many of these same stone materials were used by Ngarigo people who were custodians of this 'Monaro' landscape. Stone tools were made and used here on this land over two hundred years ago. Another site in the area has been dated as some 7,000 years ago.

References
Chappell B.W. & White A.J.R. Pluton – *Rock of the Cooma – Alpine Zone*
Whitten D.G.A. & Brooks J.R.V. *The Penguin Dictionary of Geology*

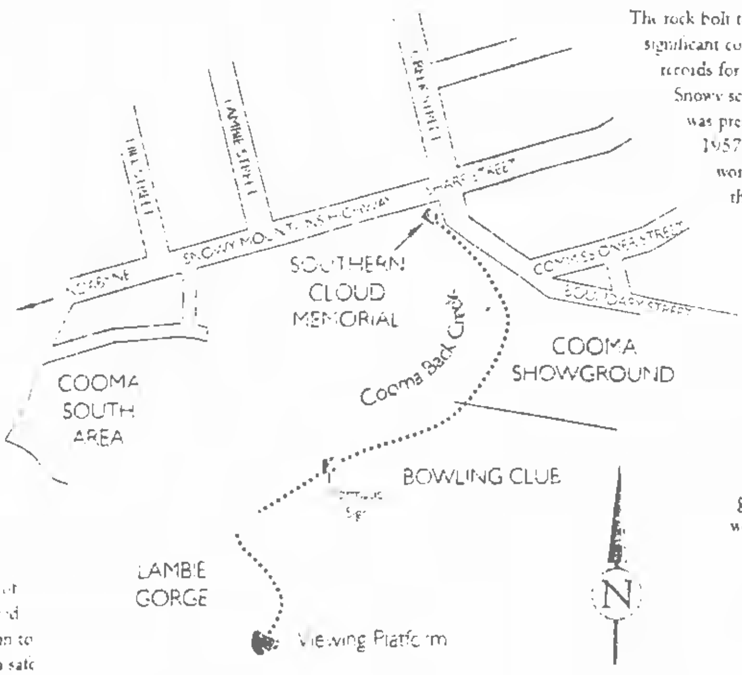


'Rock Bolt'

Australian Engineering Heritage Site

...chaeologists walked through the Lambie Gorge ...scape they would immediately spot evidence of new ...ll as old tool making technologies. Once upon ... distant time Lambie Gorge was a kind of ...tool laboratory.

... 1950s the Snowy Mountains Hydro-... ...ority designed tensioned steel rock bolts ...orm a permanent underground support system. ...se were tested on the rock face at Lambie Gorge ...d the success of the concept can be gauged in ...adoption throughout the world on a wide range of ...ificant engineering projects involving ...avations underground.



The rock bolt technique proved to be a very significant contribution to the many world records for tunnelling achieved on the Snowy scheme. The rock bolt concept was presented in New York, in October 1957 at a gathering of leading world engineers. The success of this development generated enthusiasm and pride in the Snowy organization, feelings that became integral parts of its successful work.

The technique enabled very significant savings in construction costs - by the reduction in the material excavated, the elimination of steel sets to be used, reduction in the time for construction and greatly improved construction-worker safety.

What you see at the site

The testing site has fifty or so holes drilled into the rock-blasted vertical face where pullout tests were conducted. These were tests basically to establish the best way of anchoring the bolt in the hole.

The rock bolts are inserted in a designed pattern of drilled holes immediately behind a newly excavated rock-face. They are tensioned, and then grouted in to form a reinforced rock arch – which results in a safe and permanent excavation.

An original stone cutting tool as found on Lambie Gorge site

ora

...egetation in the Reserve is a woodland community ...ck Cypress Pine and Ribbon Gum a relatively rare ...matio... Although not highly regarded for their ...r both trees can be utilised for fencing, fuel and some ...ng construction. Other types of eucalypts can also be ...n the area.

... the Gorge is only a small reserve there is ... range of shrubs and smaller plants ...ne Red-stemmed Wattle, Blackthorn, Shiny Cassinia ...with Grevillea whose flowers in early spring are ... with honeyeaters. In summer daisy bushes ...nium and grasses make a colourful display.

...g on a rocky outcrop is a patch of Elderberry Panax ... some ... a locally rare plant mainly confined ... Reserve. This is not the Elderberry of Europe from ...ine and jam are made. Nevertheless the Aboriginal ...le ate the ripe fruit of this Australian plant and ...medicinal ... from the squashed unripe berries.

Red-stemmed Wattle

Fauna

The woodland community around Cooma, of which Lambie Gorge forms a part, is home to over 80 species of birds, 5 frogs, the echidna and the platypus, 10 mammals, 4 snakes, grouped within 12 species of reptiles. One of these reptiles, the Long-necked Tortoise, chosen for the cover of this brochure, is of great significance to the Ngarigo people and to the Gorge. Of particular interest also is Rosenberg's Monitor, which can be observed waddling along during spells of warmer weather.

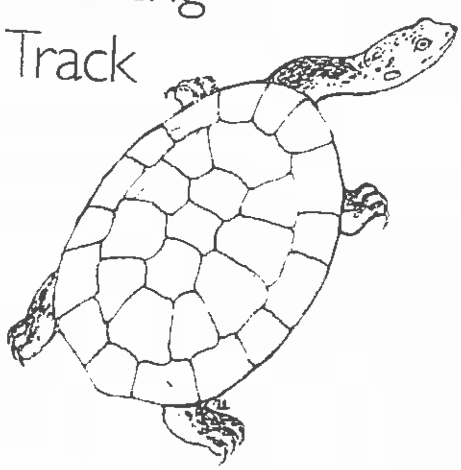
The largest dominant native fauna in Lambie Gorge is ... community of ... Wallaroos, which have been observed in the area between the Nursing Home, the Gorge and the old stone wall.

No observations of small mammals have been made up to the present time but in the past echidnas and platypuses have been seen in the Gorge area.

Many birds frequent the Gorge area; you may see hawks, parrots, kookaburras, crows, currawongs, finches and wrens. You might like to contribute to our knowledge of wildlife in Lambie Gorge by reporting your sightings to the Cooma Reconciliation Committee – you can phone your observations to:

John Gallard Ph 6456-5221 or Cooma Visitors Centre Ph 6450-1742

Lambie Gorge Walking Track



A Project of the Cooma Reconciliation Committee

&

The Monaro Ngarigo Lambie Gorge Restoration Committee

Financed by the NSW State Government Environmental Trust

European name

Following the first sighting of the extensive open grasslands of the Monaro – by Currie and Evans in 1823 – Cooma took its name from 'Kuma', the first grazing run. Coombah, a word in the Ngarigo people's language, has had two meanings ascribed to it: 'Big Lake' and "Open Country". The early surveyor, John Lambie, acquired part of the Kuma run. Lambie was later to be appointed District Commissioner for Crown Lands in the Monaro Squattage District in 1837. In 1847 he also became the District Magistrate. He died in 1862 and was buried at Christ Church in Cooma. Named in his honour are the two streets, Commissioner and Lambie, which led to his home and office situated on the present site of the Hain Centre car park. The Showground and Lambie Gorge were once known as Mr Lambie's Paddock.

The steepness of the land in the Gorge has prevented development. Some land however was cleared in the late 1800s and a stone house built there with a small orchard and some pine trees. The Committee hopes to extend the walkway to the end of the Reserve at the Chinese Wall. This is a dry stonewall that sits at the southern boundary at the upstream end of the Reserve. The wall was supposedly built by Chinese miners from the Kiandra goldfields.

During the 1980s a small reserve of Crown Land (1.042 ha) was declared. In 2003 the Cooma Aboriginal Reconciliation Committee received a NSW Government grant for the restoration of the local environment within the gorge and to enable the on-going protection of its sacred and interesting heritage.

Ngarigo place

For all its European name the Ngarigo ancestors would have had an appropriate and meaningful name for their site and hopefully one day the Gorge will reclaim its original name. Many years prior to European settlement Aboriginal women used Lambie Gorge for many purposes. One such purpose was as a place of retreat. This was where women would go to talk to the Great Spirit in order to gain inner peace, strength and wisdom to help them in their day-to-day life.

Another purpose of the Gorge was for use as a Women's Camp. These Camps were used by women and male children under the age of manhood, to learn from one another and to grow in knowledge. It was a place for women to share experiences and talk freely whilst making bonds of friendship. The women would have respected the land (Mother Earth) and the wildlife around them in the Gorge, taking only what was needed for their existence whilst there.

The conclusion that the Gorge is predominantly a women's site has been made by many experts and by talking to Ngarigo elders. Many of the stories given to us by the female elders have been passed on from generation to generation. Although no documented proof can be brought forward from those earlier days, artefacts and rock formations have verified the use of the site by Aboriginal women.

Today the Gorge, though altered in appearance, is a landscape that has been passed on to the Ngarigo descendants and, at the same time, to the whole community as a place where individuals can view the local flora and fauna in their natural forms. The Gorge also remains a place where one can gain inner strength, harmony and wisdom – for those who seek them. The dedicated work of all those of different ages and cultures, who have come along in working bees to help rescue the site, together with the respect shown this site by present day visitors, will restore it in time to its natural and abundant beauty.

Visitors who are interested in the Aboriginal significance of the Gorge might like to read

Michael Young, Ellen and Debbie Mundy

The Aboriginal People of the Monaro

Attachment 2

S.M. 1309

SNOWY MOUNTAINS HYDRO-ELECTRIC AUTHORITY

ENGINEERING CONSTRUCTION MATERIALS REPORT NO. S.M. 1309

FIELD PULL-OUT TESTS ON STRENGTHENED BAYLISS-JONES-BAYLISS QUICK-SET ROCK BOLT ANCHORAGES

Prepared by: R.T. Brodie

Reviewed by: A.D. Hocking

MAY 1962

1. INTRODUCTION

Following a request by the Resident Engineer Contract 20,045 on 12th April 1962 to carry out field pull out tests on Bayliss-Jones-Bayliss Quick-Set Anchorages, tests were carried out and established that the anchorages were produced from low strength steel (ref. 1).

Subsequent anchorages produced from steel with 60,000 and 80,000 lb/sq.in. yield stresses were submitted for testing at Materials Branch Scientific Services by the suppliers, Mills Scaffold Division, of G.K.N. (Lysaght) Pty.Ltd. Two members of the Company's staff were present during the tests.

2. CONCLUSIONS

2.1 The 60,000 lb/sq.in. yield stress anchorage developed the bolt strength, 21.5 tons, in a 45-46 mm diameter hole. However thrusting of the bolt into the hole was difficult because of the strong nature of the spring clip. It was also necessary to provide a thrust collar below the quick set spring to prevent its movement along the deformed shank of the bolt during insertion.

2.2 The 60,000 lb/sq.in. yield stress anchorage failed at 18 tons in a 47-48 mm diameter hole by pulling the cone through the expansion shell. The bolt dropped easily into the hole but setting of the anchorage was dependent upon hole surface roughness or rock joints intersecting the hole.

2.3 The 80,000 lb/sq.in. yield stress anchorage developed the bolt strength, 21.5 tons, in a 47-48 mm diameter hole. There were similar setting troubles to those experienced using the 60,000 lb/sq.in. yield stress anchorages especially when no thrust collar was used below the quick set spring.

3. MATERIALS

3.1 The Bayliss-Jones-Bayliss Quick-Set anchorages and the one inch diameter hollow core deformed shank Williams rock bolts were supplied by Mills Scaffold Division of G.K.N.-Lysaght Pty.Ltd.

3.2 The tests were carried out in an outcrop of Cooma Gneiss behind the Materials Branch, Scientific Services in Cooma Back Creek. The holes had been drilled using 44 and 46 mm drill bits, however, due to insufficient air pressure when drilling, the top part of the hole was distorted making it impossible to measure accurately the true diameter of the hole at the point where the anchorage was tested.

3.3 The bolts were pulled out using a 30 ton centre hole jack, and all movements were measured using 0.001 in. dial gauge.

4. METHODS

4.1 The anchorage was screwed on the bolt till the corrugated surfaces of the expansion shell were parallel. The bolt and anchorage assembly was then inserted in the drill hole and then at the appropriate depth, in this case 15 in., jerked towards the mouth of the hole thus obtaining a set. The bearing plate, tapered washers, jack, washers and nut were then placed on the bolt. The nut was then subjected to a torque of 250 ft. lb.

4.2 Strain gauges were placed to read movements of the anchorage and changes in the length of the bolt.

4.3 The jack was loaded slowly until the bolt failed. The dial gauges readings were read until failure seemed imminent.

5. RESULTS

5.1 Test No. A. The hole was drilled with a 44 mm drill bit. The anchorage was of the 60,000 lb/sq.in. yield stress group and was fitted with a thrust collar below the quick-set spring.

Table No. 1

Load Tons	Anchorage Movement in.	Extension of Bolt in.	%
8	.000	.000	.00
10	.003	.008	.05
12	.014	.014	.09
12.5	.096	.047	.31
13.5	.164	.166	1.11
15.5	-	-	-
17.0	-	-	-
19.0	-	-	-
20.0	-	-	-
20.5	thread stripped	-	-

Fracture occurred by the nut thread stripping after a total movement of the top of the bolt of 2.9 in. The nuts were not of the type used on production units and were inferior in several respects. They were not supplied by C.K.N. Lysaght Pty.Ltd.

5.2 Test No. B. The hole was drilled with a 44 mm drill bit. The anchorage was of the 60,000 lb/sq.in. yield stress group and was supplied with a thrust collar. A cone replaced the nut to prevent stripping of threads in the non production nuts which were the only ones available.

Table No. 2

Load Tons	Anchorage Movement A in.	Extension of Bolt in.	%
0	.000	.000	.00
5	.019	.047	.31
8	.037	.058	.39
10	.073	.068	.45
12	.153	.079	.53
13.5	.264	.104	.69
15.5	.324	.118	.79
17	.358	.292	1.95
18	-	-	-
19	-	-	-
19.5	-	-	-
20.0	-	-	-
21.5	-	-	-
22	bolt broke	-	-

Fracture occurred by the bolt breaking in the threaded length after total movement of the top of the bolt of 2.2 in.

5.3 Test No. C. The hole was drilled with a 44 mm drill bit. The anchorage was of the 60,000 lb/sq.in. yield stress group and was supplied with a thrust collar. A cone replaced the nut to prevent stripping of threads.

Table No. 3

Load Tons	Anchorage Movement in.	Extension of Bolt in.	%
0	.000	.000	.00
5.5	.034	.026	.17
8	.052	.035	.23
10	.068	.042	.28
12	.084	.048	.32
13.5	.140	.060	.40
15.5	.224	.086	.57
17.0	.346	.238	1.59
19.0	-	-	-
20.0	-	-	-
20.5	-	-	-
21.5	-	-	-
22.5	-	-	-
23.5	bolt broke	-	-

Fracture occurred by the bolt breaking in the threaded length after a total movement of the top of the bolt of 2.4 in.

5.4 Test No. D. The hole was drilled with a 46 mm drill bit. The anchorage was of the 60,000 lb/sq.in. yield stress group and was without a thrust collar. A cone replaced the nut to prevent stripping of the threads.

Table No. 4

Load Tons	Anchorage Movement in.	Extension of Bolt in.	%
0	.000	.000	.00
5	.028	.070	.47
8	.030	.082	.55
10	.037	.095	.63
12	.036	.104	.69
13.5	.159	.120	.80
15.5	.369	.141	.94
16.0	-	-	-
17.0	-	-	-
18.0	2.30 Anchorage failed	.70	4.7

The anchorage failed by the cone pulling through the shell after a total movement of the top of the bolt of 3.0 in. The maximum diametrical measurement of the cone before and after test were 39.5 mm and 34.0 mm respectively.

The remains of the anchorage were removed from the hole and numerous attempts were made to set a second anchorage in the same hole. These all failed and no anchorage could be obtained.

5.5 **Test No. E.** The hole was drilled with a 46 mm drill bit. The anchorage was of the 80,000 lb/sq.in. yield stress group and was without a thrust collar. A cone replaced the nut to prevent stripping of the threads. There was a movement of the complete bolt and anchor assembly of 1.5 in. before a set was obtained.

Table No. 5

Load Tons	Anchorage Movement + Extension of Bolt in.
15	.25
17	.25
19	.5
21.5	1.0
19	2.0
22.5	2.5 bolt broke

Failure occurred by the bolt breaking in the threaded length after a total movement of the top of the bolt of 2.5 in.

6. DISCUSSION

6.1 The true diameter of the holes in which the anchorages were placed can be taken as "The drill bit diameter + 1 or 2 mm".

6.2 Thrust bearings were not always necessary using deformed bolts in the large holes, however it was noticed in one case, in a hole drilled with a 46 mm bit, that the complete spring had moved up over the bolt deformations.

6.3 The anchorage failure, with the 60,000 lb/sq.in. yield stress anchor in the 46 mm drill bit hole, was caused mainly through large plastic flow developing in the cone. A larger load could have been realised if a cone, made from 80,000 lb/sq.in. yield stress material, and an expansion shell, from 60,000 lb/sq.in. yield stress material, had been combined and used.

7. ACKNOWLEDGMENTS

The Author is indebted to Messrs. Wansink and Ali for their help during the testing program, and to members of the staff of G.K.N. Lysaght Pty.Ltd. who also provided assistance.

Attachment 3

SNOWY MOUNTAINS HYDRO-ELECTRIC AUTHORITY

Grouted Rock Bolts for Permanent Support of Major Underground Works

By

E. B. Pender, M.E., B A., A.M.I.E.Aust.,

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1963

Grouted Rock Bolts for Permanent Support of Major Underground Works

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and

R. H. MATTNER, B.E.(Mining) (*Associate Member*)*

Summary.—For some years, rock bolts have been used on a large scale by the Snowy Mountains Authority for support of underground excavations during construction. Since 1958, they have been used to an increasing extent as permanent support

The paper reviews, with particular regard to the new works commenced in 1961 and 1962, recent developments in rock bolt design, and in the practices and procedures of installation under conditions of rapid tunnel excavation. Where the bolt is to be part of the permanent rock support system, grouted deformed shank bolts are now standard ; the structural advantages of these are described. The results of " pull-out " and other tests on bolts having various types of shank treatment are given.

1.—Introduction.

Although rock bolts have been used for roof support in mining practice for a considerable time (Ref. 1), they did not come into general use in civil engineering underground work until the construction of the Keyhole Diversion Tunnel in Wyoming in 1950. The East Delaware Aqueduct for the New York water supply was constructed in 1950-1952 using rock bolts as support over 12 miles of tunnel of 11 ft. 4 in. dia. driven through flat bedded shales and sandstones. In the Kemano Power Station in British Columbia, rock bolts were used for the temporary support of the roof of the machine hall which was 700 ft. long, 83 ft. wide and 120 ft. high, excavated in hard granite. In France, the large underground power stations of Randens and Serre-Poncon were also constructed using rock bolts as temporary support.

In the Snowy Mountains, some rock bolts were used in the Guthega Project (excavated 1952-54), but the first major use of rock bolts in the Authority's works was in Tumut 1 Power Station (excavated 1956-57).

The volume of the permanent underground excavations completed on the Snowy Mountains Scheme up to October, 1962 was approximately 3,500,000 cu. yd. Included in this total were 50 miles of major tunnels and four large chambers for machine halls and transformer halls. Fig. 1 shows one of these during excavation.

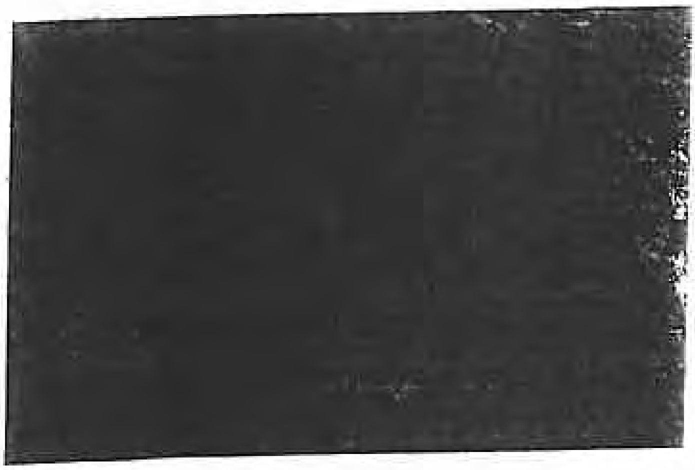


Fig. 1.—Grouted Rock Bolt Support of Tumut 2 Machine Hall Roof where 5,220 Bolts were Installed.

Approximately two-thirds of this volume was excavated using rock bolts as the primary support, and on a substantial proportion of the works the rock bolts were grouted and used as the only permanent support over large areas. A total of 97,221 bolts had been installed up to November, 1962, of which 57,850 were gro[u]
Tables I and II set out some details of these works.

2.—Theory of Rock Bolt Support.

2. (a) General:

Support of rock by bolts is fundamentally an entirely different process from support by steel or timber sets. Conventional methods of designing steel or timber sets, if design calculations are attempted at all, assume that a certain volume of rock acts as a dead load.

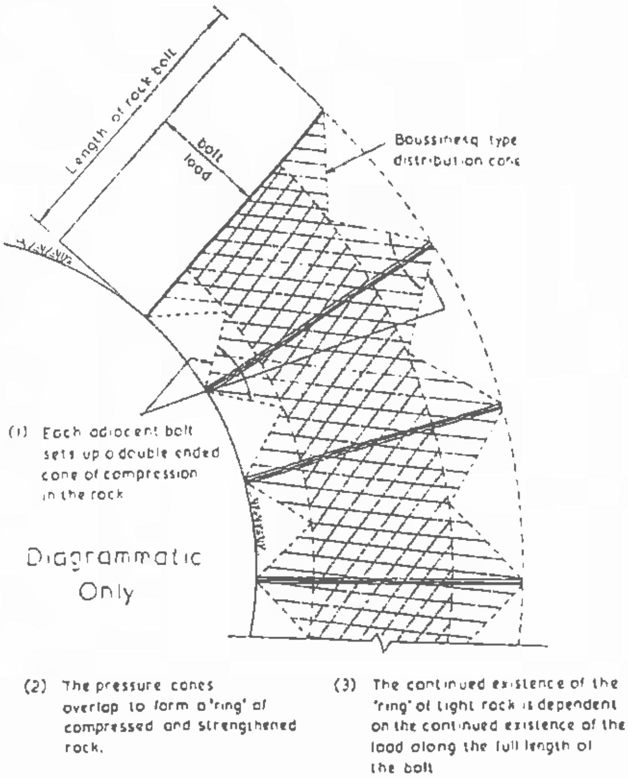


Fig. 2.—Action of Rock Bolts on the Rock around an Excavation.

*This paper, No. 1726, was presented before the Engineering Conference, 1963, in Adelaide from 29th April to 3rd May, 1963.

Mr. Pender, the senior author, is Senior Executive Engineer, Civil Engineering, Snowy Mountains Hydro-electric Authority. Mr. Hosking is an Executive Engineer of Scientific Services Division of that Authority engaged on soil and rock mechanics and Mr. Mattner is an Engineer of its Major Contracts Division engaged on supervision of tunnelling operations.

TABLE I.
Major Tunnels.

Tunnel	Excavation size	Length of tunnel (ft.)	Construction support: Percentage of length: Un-supported	Rockbolts	Steel sets	Number of rock-bolts	Permanent support: Percentage of length: No support	Grouted rockbolts	Concrete lining	Number of grouted rockbolts	Date completed
Eucumbene-Tumut	24 ft. Circular	72,810	82	Isolated only	18	Few only	71	—	29	None	August 1957
Tumut 1 Pressure	24 ft. Circular	8,217	75	Isolated only	25	Few only	—	—	100	None	July 1956
Tumut 1 Tailwater	25 ft. 6 in. by 28 ft. Horseshoe	3,149	1	51	48	7,815	1	44	55	3,200	June 1958
Tumut 2 Pressure	23 ft. Circular	15,405	65	22	13	6,818	—	—	100	None	March 1960
Tumut 2 Tailwater	23 ft. Circular	20,049	31	23	46	10,083	—	—	100	None	March 1961
Tooma-Tumut	13 ft. 5 in. Horseshoe	46,603	68	17	15	10,737	61	17	22	9,069	February 1960
Murrumbidgee-Eucumbene	11 ft. 10 in. Horseshoe	54,617	47	40	13	20,269	47	35	18	19,303	May 1960

Depending on the lay of the strata or, in igneous rock, the joint system, the mass of rock assumed as the design load may have various shapes (Ref. 2).

The fact that rock bolting provides a positive force on the rock and provides a stressed membrane distinguishes it from steel or timber support and from the practice of grouting unstressed anchor bars.

While rock bolting can be used merely to pin back individual rocks, the term now generally refers to the designed use of bolts to develop jointed rock into a structural entity. When used in appropriate patterns, the bolts create a principal compressive stress normal to the free surface of the excavation, and this, in turn, creates a zone of rock which acts as a structural membrane capable of providing its own support (Fig. 2). This has been demonstrated both photo-elastically and by models (Refs. 3, 4, 5).

In the case of *in-situ* jointed rock, each block occupies a cavity of its own size and shape, except to the extent that the joints are open. Experiments have shown that bolts can in fact support rock masses which are in a much more discontinuous condition, such as masses of aggregate, provided that there is proper relationship between the length and spacing of bolts and the aggregate size. Wire mesh or other supplementary support is then required only to prevent the fall of particles from the shallow tension zones between the bolts. Fig. 3 illustrates application of this principle to jointed rock.

An underground excavation where rock bolting was successfully used as support for material in an advanced stage of chemical disintegration is described by Rabcewicz (Ref. 6). Rock bolting on the Snowy Scheme has not been extended to such limits. Apart from reasons of prudence, there is an economic limit to the use of rock bolts in soft materials. Anchors have to be larger, which means more costly drill holes and the use of more auxiliary supporting material between the bolts.

The theory and practices of rock bolting in igneous and metamorphic "hard" rocks, such as those of the Snowy Mountains, are different in many ways from those applied in coal mines and other works in which the dominant geological feature is bedding at angles near the horizontal (Ref. 1). The engineering characteristics of the rock masses to which this paper applies are set out in Table III as Classes 3, 4 and 5.

2. (b) *General Theoretical Considerations:*

Theoretical analyses of the stress situation around an excavation supported by rock bolts has been developed principally by French authors (Refs. 7 and 8). The Mohr circle and its later

TABLE II.
Other Major Excavations.

Excavation	Dimensions		Construction support: No. of rockbolts	Steel sets	Permanent support: No. of rock-bolts grouted	Concrete lining	Date completed
Tumut 1 Machine Hall	306 ft. long 77 ft. wide 105 ft. high	roof	2,194	Light arch steel supports and posts	None	Arch ribs	May 1959
		walls	1,122		861		
Tumut 1 Transformer Hall	127 ft. long 73 ft. wide 44 ft. high	roof	1,366		None	Arch ribs	May 1959
		walls	123		83		
Tumut 2 Machine Hall	320 ft. long 51 ft. wide 110 ft. high	roof	2,553	Heavy steel supports—six only	2,553	Arch ribs	Nov. 1961
		walls	3,220		3,220		
Tumut 2 Transformer Hall	172 ft. long 47 ft. wide 47 ft. high	roof	1,212		1,212	Arch ribs	Nov. 1961
		walls	274		274		

Fig. 3—Use of Rock Bolts and Wire Mesh in Class 2 Rock in the Shaft of Murrumbidgee-Eucumbene Control Structure.

elaborations are applied to determine the general nature of the stresses in the rock around the excavation. Terzaghi and Richart (Ref. 9) and others (Ref. 10) have also made significant contributions to rock stress theory. The scope of this paper does not allow of more than a short survey of the rock mechanics factors in rock bolting and the citing of references which are complementary to this paper.

There are two gaps between purely theoretical results and the actual situation in rock excavations:

(i) the formulae of the theory of elasticity refer to homogeneous isotropic bodies, whereas rock as met with in construction usually has different properties according to the stress fields imposed, and usually the joints are sufficiently well developed to make it fundamentally a discontinuous body;

(ii) any stress distribution calculations must start from knowledge of or assumptions concerning the stresses already existing in the rock before excavation. There is the stress due to the weight of the rock and soil above, and, accompanying that, a conjugate horizontal stress. These stresses, however, may be quite overshadowed in magnitude by stresses due to topographical or tectonic conditions which generally give rise to higher horizontal stresses than theory would suggest. Means exist for measuring these stresses and numerous measurements were made in the Upper Tumut Works (Refs 11, 12, 13). In the absence of such measurements, Heim's hypothesis of a hydrostatic stress condition is often assumed for deep excavations. However, it is difficult to predict stress conditions, particularly horizontal stresses, and field stress measurements should be made for all important excavations.

In that zone of the rock mass which is immediately adjacent to an opening made by blasting, a third factor operates. Joints open up and the capacity of the rock to sustain stress may be much below that of the same rock in an undisturbed condition. Fig. 4 shows the theoretical stress distribution in a homogeneous isotropic body which, before the excavation of the opening, was under hydrostatic stress conditions. Fig. 5 shows the modification if there is a zone of loosened material around the opening.

In an excavation, some of the loosened rock is removed but most of it remains; the general objective of rock bolting is to reinforce this remainder and at the same time bind it to the relatively unaffected rock behind.

2. (c) *Behaviour of Masses of Jointed Rock:*

Joint patterns and weaknesses dominate the rock behaviour in excavations (Ref. 14). The strength of the rock, as found by laboratory tests on sound blocks, is not necessarily an indication of the behaviour of jointed rock *in situ*. Such test results are relevant only in cases where there is concern with the capacity of an individual block to carry local concentrations of stress. The only type of laboratory test which could be of value in assessing

TABLE III.

Rock Classification and Support Practice.

Rock class	Rock condition	Characteristics	Typical support used on works of the Snowy Mountains Authority
5	Excellent	Sound, compact, usually dry rock, either unjointed or with tightly closed, strongly cemented joints. Tends to break across the rock itself on excavation, rather than along joint planes, hence the traces of blast holes usually remain.	No support, except in large excavations such as power stations.
5S	Excellent (but highly stressed)	As above, but "spalling" or "popping" occurs.	Not as yet encountered on these works.
4	Good	Hard rock generally dry with tightly closed, weakly cemented joints; some slightly open joints with water seepages or flows may occur. May contain some narrow sheared or crushed zones. Tends to break along the weakly cemented joints on excavation, rather than across the rock itself. The percentage breakage along joint planes in any particular case largely depends upon the orientation of the excavation surfaces in relation to the main joint directions.	Mainly unsupported or with few rock bolts to pin shoulders, if orientation of excavation is adverse in relation to main jointing. Generally less than one bolt per linear ft of 2[illegible] tunnel.
3	Very fair	Mainly hard rock, but considerably loosened by the opening up of weakly cemented joints on excavation, or due to the presence of slightly open joints, or narrow sheared or crushed zones. May be dry but usually wet. Tends to break entirely along joint planes on excavation, regardless of the orientation of excavation surfaces in relation to the joint planes.	Light steel sets or "completely" supported in roof by rock bolts, occasionally supplemented by steel channels and wire mesh. Usually 2 to 3 bolts per linear ft. of 20 ft. dia. tunnel.
2	Fair	Partly hard rock but usually containing more than 10 per cent of soft material classifiable as soil, i.e., crushed zones, loosely jointed sheared zones or highly to completely altered zones.	Generally heavy steel sets in tunnels and light steel sets, or rock bolts, with mesh in shafts.
1	Poor	Consists of more than 50 per cent soft material classifiable as soil, i.e., crushed zones, loosely jointed sheared zones or highly to completely altered zones. Can be excavated without the use of explosives. Exerts pressure on supports.	Generally heavy steel sets with close timbering in both tunnels and shafts. Invert struts occasionally [illegible]quired in [illegible]nels.
0	Very poor	Consists entirely of soft material classifiable as soil, usually crushed or completely altered rock. Exerts pressure on top and sides of supports. Includes squeezing and swelling ground.	Heavy steel sets at close spacing in both tunnels and shafts. Invert struts required in tunnel. Timber or steel spiling required. Pilot drifts and other special tunnelling techniques possibly required.

behaviour of a rock mass would be one obtained from a specimen of such size that the joint spacing was negligible in comparison. Where the joint spacing is of the order of 2 in., tests on a 36-in. by 12-in. dia. cylinder would probably be of value. In this case,

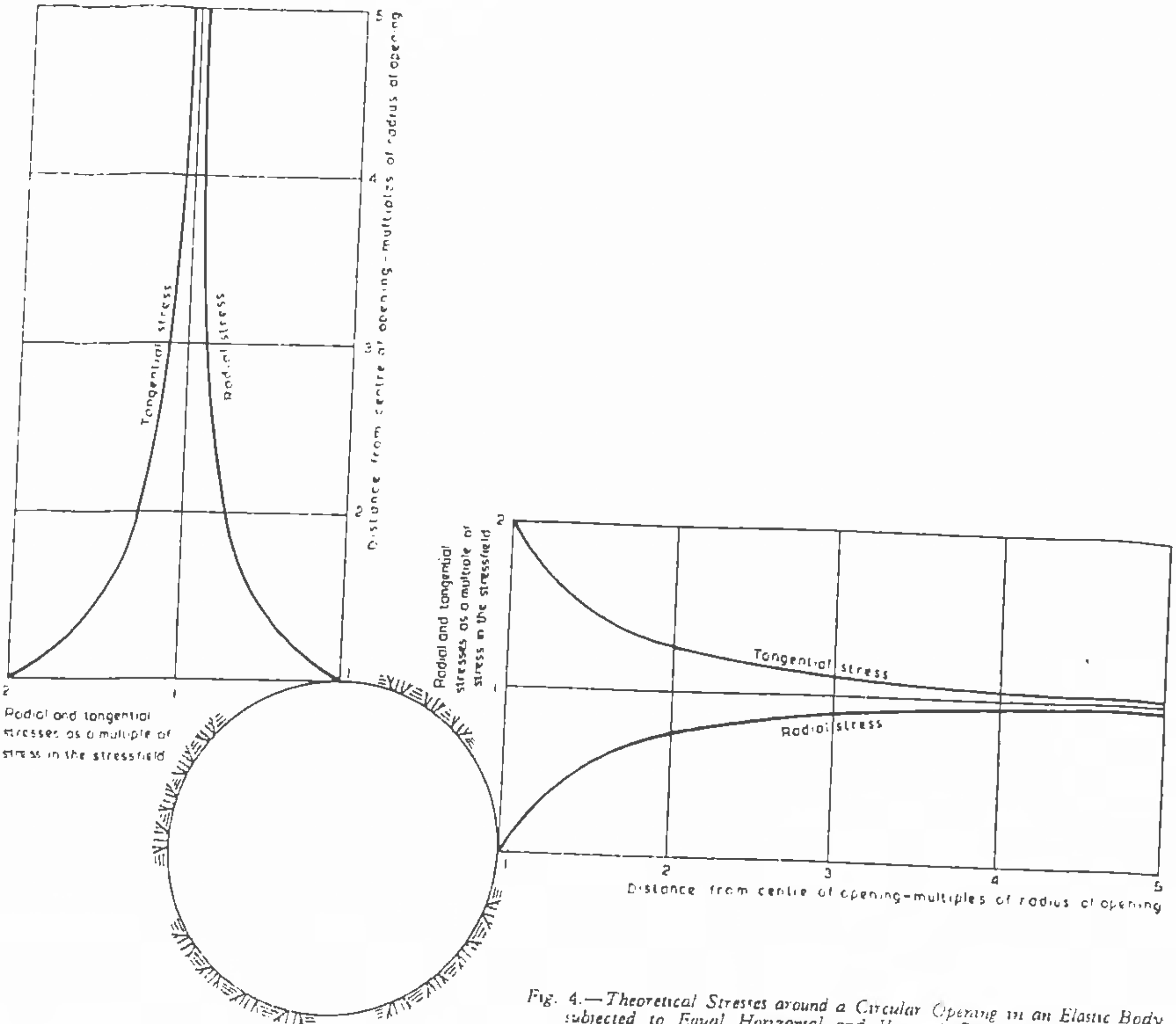


Fig. 4.—Theoretical Stresses around a Circular Opening in an Elastic Body subjected to Equal Horizontal and Vertical Compressive Forces

the triaxial compression test on soils could well be imitated, although the cost would be high.

The deformation properties of a rock mass, and the extent to which it is non-elastic and anisotropic, is basically determined by the mobility of the individual blocks which together make up the mass. Any open jointed rock mass underground is usually a two-phase system of rock particles and water—a condition which promotes mobility. Measurements of any kind on rock masses yield data with a wide scatter and any individual observations have to be regarded with caution.

One important feature in connection with rock bolting is that the quality of the rock bolt support achieved is related to the promptness with which bolting is carried out after blasting. Until the rock either collapses or reaches equilibrium, movements occur which are progressive in one case and decreasing in the other: the more quickly a positive restraining force is provided, the more the rock can contribute to its own support (Ref. 15).

A characteristic property of jointed rock is creep under repetition of load cycles (Fig. 6). A considerable amount of *in-situ* measurement of these properties was carried out on the Upper Tumut works (Ref. 12). Creep occurs if the rock is not bolted until some time after excavation, or if tension on the bolts is released for a time.

2. (d) The Advantages of Rock Bolting:

The principal structural advantage of rock bolting is that it applies a positive force to the rock. Steel sets, on the other hand, cannot exert full restraining force on the rock until the rock has already moved, except to the extent that lagging has been wedged tightly between the sets and the rock. The result is that the sets ultimately have to support a greater weight of rock than should have been necessary.

The principal practical advantage of rock bolting is that it can be carried out simultaneously with face drilling and other routine work, whereas the installation of steel sets, because of their size and awkwardness, disrupts all routine activities.

The use of rock bolts as an alternative to light steel sets avoids the enlargement of the tunnel section and, in marginal ground, the possible increased difficulties of support. Rock bolts can also be used to provide support to the extent and in the position required. If steel sets are the only support used, a full set must always be used, even though support is required at only one point on the periphery (Fig. 7).

Rock conditions usually change with some degree of graduation. Rock bolts provide a convenient means of transition—no support, occasional bolts, full bolt patterns and, finally, steel sets, and then out again through the reverse sequence.

During construction of wide underground excavations, rock bolts allow better lighting, access and ventilation than would be the case if they were supported by steel of beam and post design. Moreover, the readiness with which the effectiveness of the bolt can be checked has a safety morale value.

Lang (Ref. 3) estimated that the quantity of beam and post support which would have been required in Tumut 1 Machine

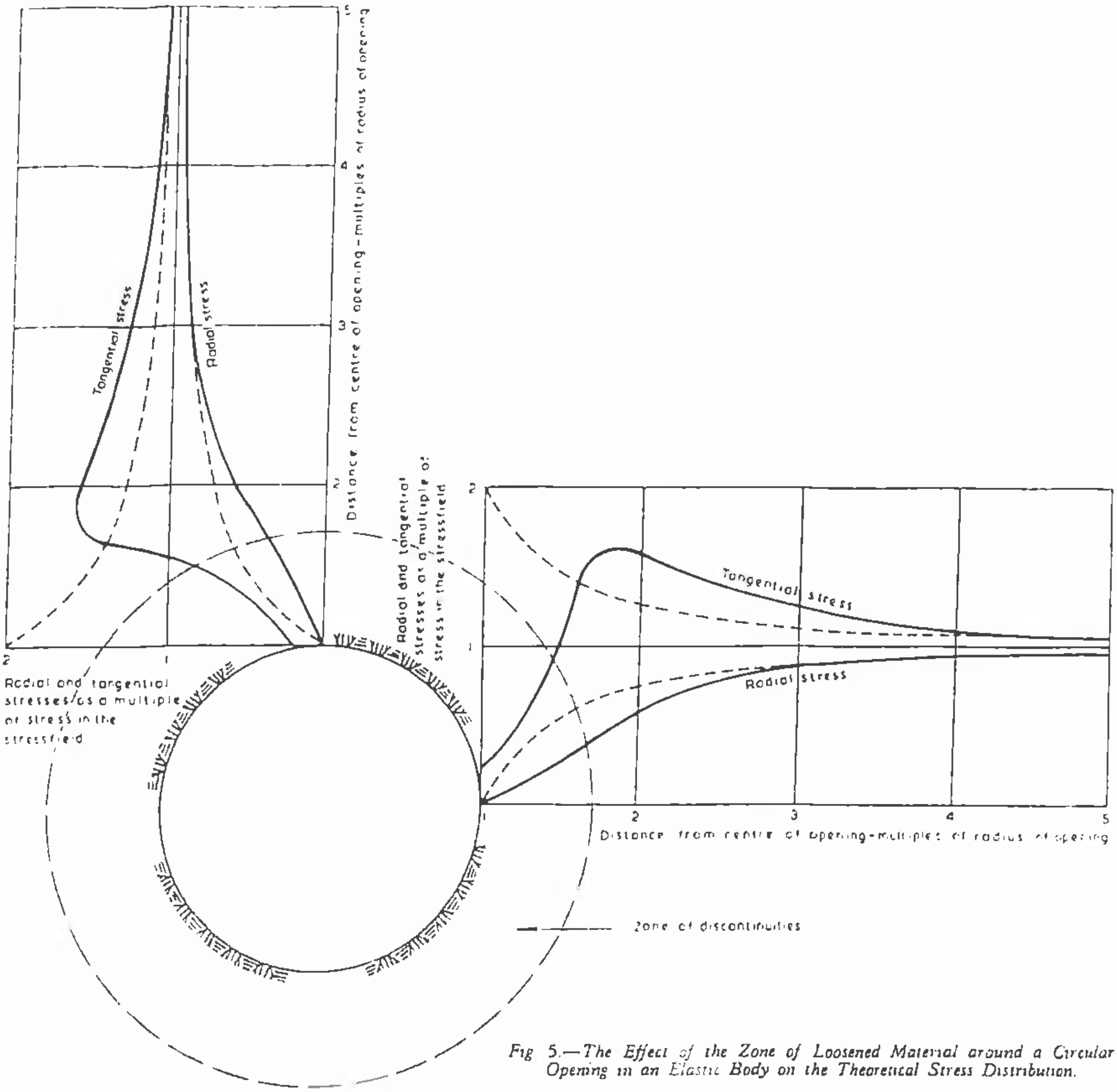


Fig 5.—The Effect of the Zone of Loosened Material around a Circular Opening in an Elastic Body on the Theoretical Stress Distribution.

Hall roof would have been eight times the weight of steel used in rock bolts and that the cost would have been five times as much.

In tunnels which are to be concrete-lined only in those sections where rock conditions make it necessary (" partially lined tunnels "), the amount of lining required is considerably less where rock bolting is used than where only steel sets are used. Any section where steel sets have been placed is, in Snowy Mountains Authority's practice, always concrete-lined because of the need to make the support permanent. In a rock-bolted section, steel mesh and pneumatically applied mortar may be used in place of concrete. Because a major part of the cost of concrete lining is the cost of setting up forms, a minimum length of lining of 30 ft. is adopted. When rock bolts and pneumatically applied mortar are used small areas of weakness may be protected locally.

If it is decided to concrete-line a rock-bolted section the amount of concrete required is less than if the section had been enlarged to take sets. For a 21 ft. dia. tunnel, the amount of " pay " concrete per foot with rock bolts and with steel sets is typically 2.8 cu. yd. and 3.9 cu. yd. respectively.

The effect of rock bolting on costs may be illustrated by comparing the total costs per foot of rock-bolted sections and steel-supported sections, firstly in fully lined tunnels and secondly in nominally unlined tunnels.

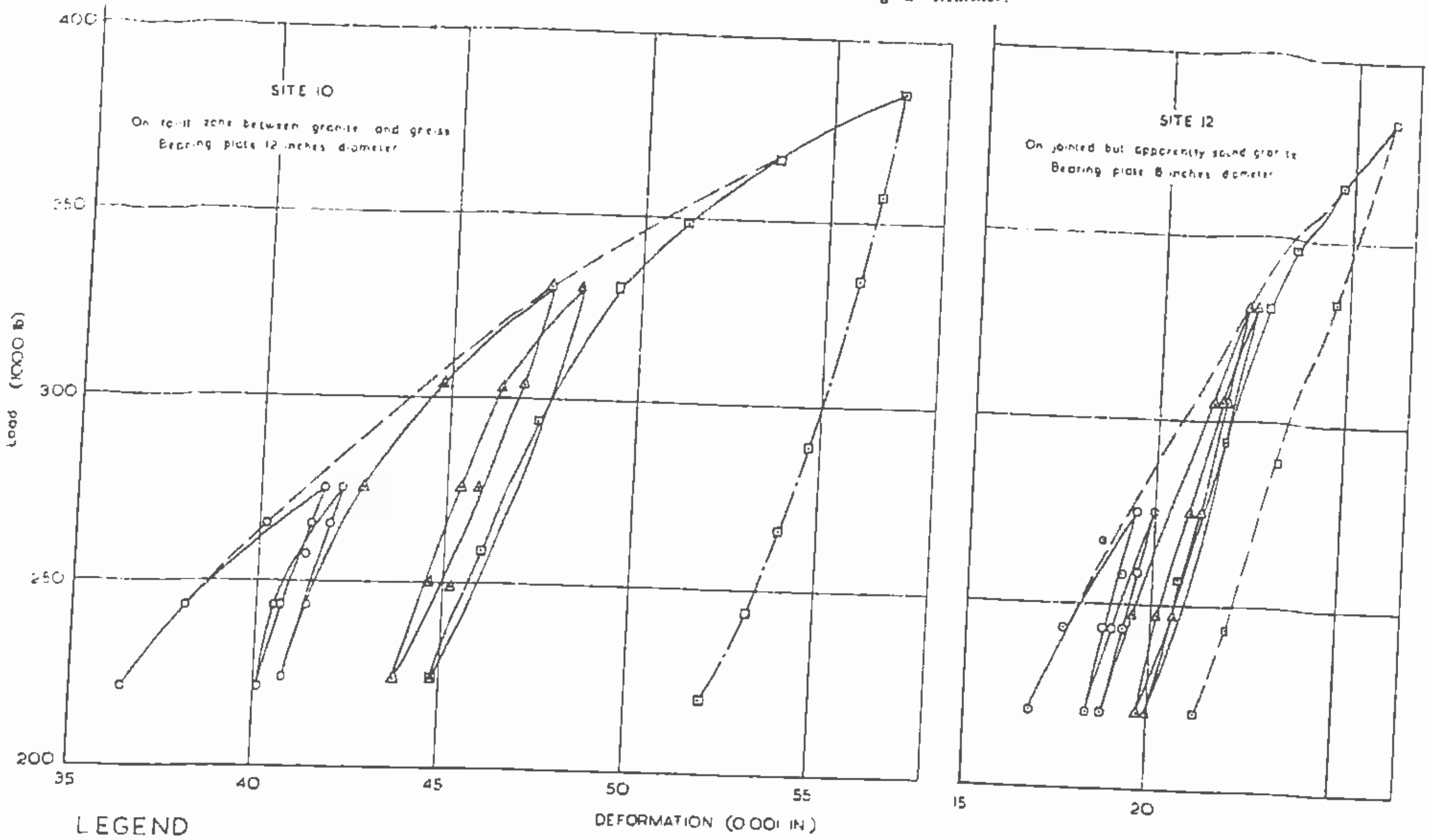
In fully lined tunnels the effect of using light steel set support in lieu of rock bolts is to increase the total cost per foot by some 45 per cent. In nominally unlined tunnels the difference is even more marked. The effect of using light steel set support in lieu of rock bolts is to increase the total cost per foot by 100 per cent, largely due to the cost of protecting the steel sets with concrete. The fact that rock bolts and light cladding can be restricted to the areas where they are actually needed, results in further savings.

3.—General Considerations Governing Rock Bolt Practice in the Works of the Snowy Mountains Authority.

3. (a) *Classification of Hard Rock by Condition with Regard to Behaviour in Excavation :*

The term " rock condition " is used to describe the state of a rock mass, together with any joints, sheared zones, crushed zones, or altered zones which occur in it.

The classification used by the engineering geologists of the Snowy Mountains Authority, set out in Table III, is for hard rocks and is based on rock conditions, substantially without regard to petrological classification.



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O Loading 1 & 2	220000 = 275000 lb
△ Loading 3 & 4	220,000 = 330,000 lb
□ Loading 5	220000 – 380000 lb

Fig. 6.—Load v. Deformation Relation obtained by Rock Bearing Tests. Exploratory Tunnel, Tumut 2 Power Station.

Definitions of some of the geological terms used in this Table are given in Fig. 14.

Rock bolting is carried out wherever the joints or other natural discontinuities are open (as indicated for instance by limonite staining), or are lined with clay, or are smooth and uncemented. Other factors taken into account are the orientation of joints or discontinuities in relation to the tunnel line and the spacing between them.

3. (b) Length and Spacing of Bolts:

The factors which determine the length and spacing of bolts are:

(i) the estimated depth of the loosened zone,
(ii) the joint spacing, and orientation, and
(iii) the diameter of the tunnel or the width of the excavation.

Practice in Europe is to compute, from measured or estimated properties of the rock, a unit pressure in tons per sq. ft. required to be applied to the exposed surface of the rock in order to hold it in place (Refs. 7, 8), and to adopt bolt spacings which give this unit pressure. It is believed that this method applies primarily where the rock is soft or in an advanced stage of disintegration. In the Snowy Mountains the individual blocks of rock are normally hard and the rock bolting pattern is based on joints and weaknesses, mostly without any particular attention to support pressures.

The following working rules have been set up from experience with the rock so far met with in the Snowy Mountains Area.—

1. The ratio of bolt length to bolt spacing should be not less than 2. This is to ensure that overlap of zones of pressure between adjacent bolts is sufficient to create a zone of approximately uniform compression with a thickness equal to about one-third of the bolt length (Fig. 8).
2. The length of the bolt should be not less than three times the width of the joint blocks.
This is to ensure that the anchorage takes place in blocks not less than two layers behind the surface, although four blocks behind would be preferable. For the average granite of the Snowy Mountains, this criterion results in a minimum bolt length of 8 ft.
3. Practice on Snowy Mountains works is to aim at a bolt spacing and tension sufficient to create a compression of 10 lb./sq. in. in the zone of uniform compression.
4. In large excavations the rock bolts should be longer than in small excavations in the same conditions.

Fig. 7.—Rock Bolt and Steel Set Support in Class 3 Rock in Tumut 2 Tailwater Tunnel.

Theory suggests that the depth of the zone which should be put under compression is a function of the tunnel radius. In small tunnels long bolts are difficult to handle. Practice in the Snowy Mountains Area can, in general, be expressed by the formula:

$$L = 6 + 0.0045S^2$$

where L = length of bolt in feet

S = span of opening in feet

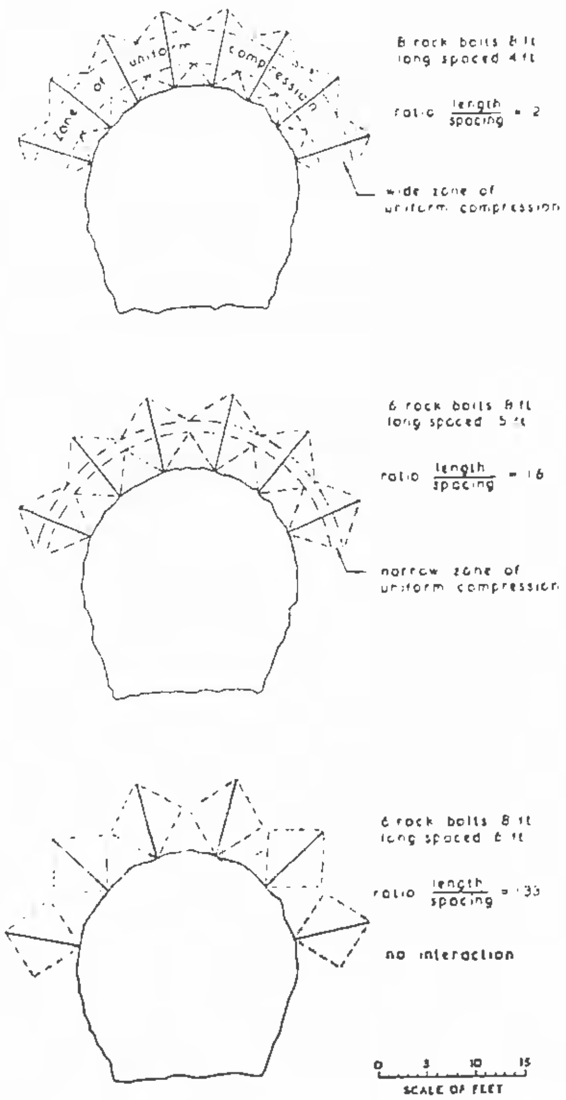

Fig. 8.—*The Effect of Rock Bolt Length-Spacing Ratio on the Depth of the Strengthened Zone for the Case of a 20-ft. dia. Tunnel and 8-ft. Bolts.*

3. (c) *Stressing the Bolt—The Torque-Tension Relationship:*

The aim is to stress the bolt to a predetermined tension. If the process by which this is done involves the simultaneous development of torsion or bending stresses on the bolt, the permissible applied tension is reduced.

In almost all types of bolt, the load is applied by rotation of the nut against the bearing plate assembly, usually by means of an impact wrench. This imposes torsion and, in some cases, bending stresses on the bolt in addition to the tensile stress. Unless a special test is made on it, the stress conditions in any particular bolt are unknown except in so far as they can be approximately deduced from the known applied torque. Much of this torque is, however, absorbed in friction at the surface of the bearing plate assembly. The remainder of the torque reaches the threads and sets up in the bolt tension due to the action of the threads and torsion due to thread friction. Bending stress due to misalignment and uneven bearing may also be present.

In earlier work (Ref. 3) an empirical relationship between applied torque and tension was obtained in the form:

$$T = kBd$$

where T is the torque applied in the nut in lb. ft.,
B is the bolt tension in lb.,
d is the nominal bolt diameter in inches, and
k is a constant.

Test results for one-inch bolts indicated an average value for k of 0.0166.

A further investigation in 1959 was directed to detailed determination of the coefficient of friction of the nut on the bolt thread, of the nut on the washer, and of the combined stress conditions in the bolt shank of both 1 in. and $\frac{3}{4}$ in. dia. bolts. The theoretical relationship between torque, tension, bolt dimensions and thread friction is:

$$T = \frac{p + \mu\pi D}{2\cos\phi(\pi D - \mu p)} BD$$

where T is the nett torque applied to the threads in lb ft.,
p is the thread pitch in inches,
ϕ is the thread semi-angle,
μ is the coefficient of thread friction,
D is the mean thread diameter, and
B is the bolt tension in lb.

The tests were performed in a 50-ton universal testing machi Torque was applied to the nut with a calibrated wrench and ι tensile load induced in the bolt was measured by the testing machine. The shear and tensile strains were measured optically.

There was a wide range in the values obtained for μ, especially at low torques. Within the range of 150 to 350 lb. ft. for 1-in. bolts and 100 to 250 lb. ft. for $\frac{3}{4}$-in. bolts, μ tended to 0.16 to 0.18 when lubrication was adequate. As torque was increased, all initially low values rose towards this range and all initially high values fell for both 1-in. and $\frac{3}{4}$-in. bolts. The coefficient of friction of the nut on the washer was found to have approximately the same values and similar behaviour with increase of load. Tests were carried out with a variety of lubricants and rust prevention compounds. It was found that bilge grease used on a surface primed with dried gilsonite-aluminium paint always gave a high efficiency.

As regards combined stress in the bolt shank, it was found that the shear stress due to torsion could be up to one and a half times the shear stress due to tension, with consequent yielding in the outer fibres of the bolt at tensions much below its capacity in pure tension. The tension at yield point was related to μ as follows.—

μ =	0	0.10	0.20	0.30	0.40
T =	21,950	18,450	15,200	11,800	9,650 lb. ft.

These investigations show that, with the torques normally used, there is a strong possibility that many bolts are, duri· installation, subjected to stresses beyond their yield point. It necessary to take into account that many of the bolts will subsequently be subjected to transient overloads from blast or natural seismic shock waves.

As, however, maximum positive force on the rock is the first requirement of a rock bolt, a compromise is adopted. A torque of 250 lb. ft. is used for 1-in. bolts of En5A steel. Under average conditions of thread and washer friction this gives a tensile force of about 15,500 lb. and, for cut threads, a safety factor of about 1.1 on yield strength at the outer fibres. The torque on 1-in. mild steel bolts with cut threads should theoretically be limited to about 180 lb. ft. In mild steel bolts with rolled threads, however, the steel in the threads, which is the critical section, has been improved by work hardening during thread rolling. A torque of 250 lb. ft. can be applied to these without apparently damaging them.

Generally, however, the variability of the factors involved in the process of tensioning bolts by applying torque is such that it has to be accepted that some bolts will be overstressed and others under-tensioned.

3. (d) *Grouting of Rock Bolts:*

On the Tumut 1 works rock bolts were intended originally as construction support only; the designs provided for all permanent support to be of concrete. The advantages shown by the bolts led to the realization that they should be made permanent, both in the Tumut 1 works, where possible, and in all future works.

Consideration was given to the use of bolts of materials less corrodible than steel. Brass, aluminium bronze, and aluminium were considered, and bolts of the last mentioned were experimented with on some works. Apart from the higher cost of the bolts themselves, the larger shanks and anchorage diameters needed large drill holes. An aluminium bolt of the same strength as a bolt of A.S. No. A 1 steel of 0.915 in. dia. has a shank of $1\frac{1}{4}$ in. dia. and a correspondingly large anchor. At this time, also, there was on the market a proprietary method of reinforcing rock by insertion of deformed steel bars in a cement mortar encasement in the drill holes by use of a perforated split cylinder. This method had the disadvantage that prestressing did not occur.

It was decided to proceed with development of a grouted rock bolt. The main difficulty was that the space left by a 1-in. bolt in a $1\frac{3}{8}$-in hole allowed of the use only of very small diameter tubes. The alternatives of a larger diameter drill hole or an enlarged collar section were discarded on account of cost. The key to the problem was to develop a grout which would have both adequate strength and flowability. Various formulations of cement, sand, pozzolans and additives and methods of placing the grout in the bolt hole were investigated. It was found that a neat cement grout of about 0.40 water-cement ratio, made with a selected portland cement, could be placed with a simple apparatus (Ref. 16).

One advantage of grout is that it provides an alkaline environment for the bolt shank and anchor. It also fills the hole completely with a strong material which enables the bolt to offer shear resistance to forces acting in a plane perpendicular to the axis of the bolt. If the anchorage or bearing plate fails, the bolt load is transferred to the rock by means of the grout bond. In addition, the grout forms a sound filling for any rock crevices adjoining the hole.

If the joints are open enough to take an appreciable quantity of grout, the ring structure created by the rock bolts can be regarded as almost a low-grade reinforced concrete. If the joints are too tight to take grout, the result is a dry masonry reinforced with prestressed steel bars.

3. (e) *The Exposed Parts of the Rock Bolt:*

The protection given to the shank of the bolt by the grout should be matched by equally good protection of the exposed parts of the bearing plate assembly and the bolt shank. In general, this has been achieved only to everyday standards. On the other hand, major engineering works such as the tunnels of the Snowy Mountains works should be prepared for a life measured at least in hundreds of years. It is difficult to achieve absolute permanency - corrosion-prone components under continuous immersion: the problem has been dealt with by making the role of the bearing plate less essential in the later life of the bolt.

3. (f) *Rock Bolts with Deformed Shanks:*

While the bearing plate assembly is likely to fail by corrosion, the anchorage could also fail by softening of the rock under the pressure of the anchor and the presence of water.

If either or both of these things happen, the bolt will maintain its pre-stress only to the extent that the adhesion between the bolt shank and the grout can maintain the tension in the bolt. If the bolt is a plain bar, the first assumption which can be made is that approximately thirty bar diameters would be required to develop bond. The resultant reduced effective length of the bolt is especially important on bolts of the most commonly used lengths—about 8 ft.

The effect on the ring of reinforced rock is shown in Fig. 9. The thickness of the zone of uniform compression is decreased to an extent which depends on the ratio of bond distance to the length of bolt and to the bolt spacing. Moreover, the rock in the tension zones between the bolts is not supported to the same extent as before. If, on the other hand, bolts with enhanced bond capacity are used, the situation after failure of the bearing plate and anchorage would be generally as shown in Fig. 10. Here, the cones of pressure of the bolts are still about 75 per cent of their original volume. The layer over which the pinning-back effect is lost is now much less than is the case in Fig. 9.

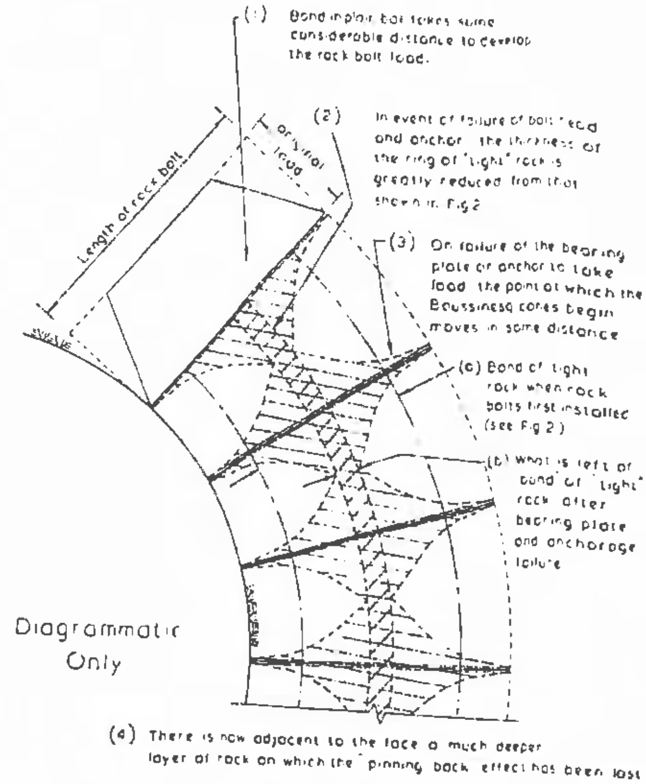

Fig. 9.—The Effects of Failure of Rock Bolt Anchorage and of Bearing Plate on the Support System shown in Fig. 2—Plain Shank Bolts.

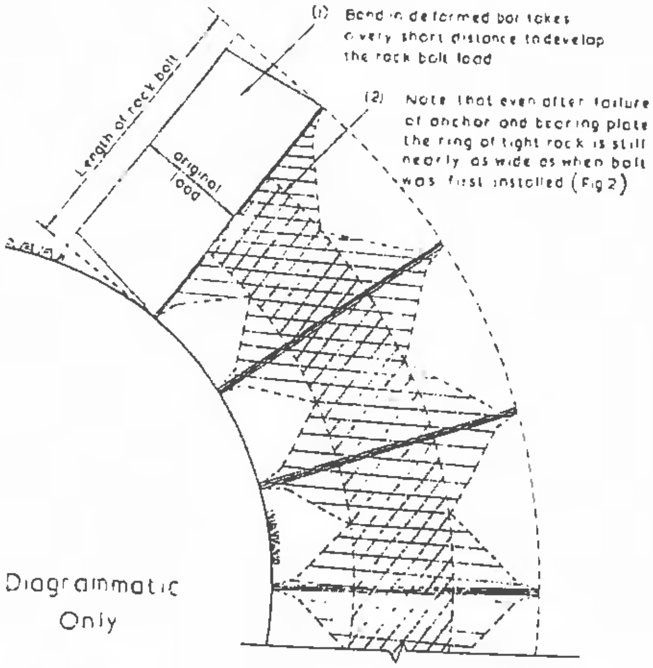

Fig. 10.—The Effects of Failure of the Rock Bolt Anchorage and of the Bearing Plate on the Support System shown in Fig. 2.—Deformed Shank Bolts.

TABLE IV.

Properties of Steel in Rock Bolt Shanks subjected to "pull-out" Tests.
(One-inch nominal diameter—hollow core)

No.	Type of bar	Type of steel	Type of deformation	Minimum bar dia (in.)	Weight/ft. length (lb.)	Tests on bar stock: Yield load (lb.)	Tests on bar stock: Ultimate load (lb.)	Tests on bar stock: Elongation on 8-in. length (per cent)	Tests on 8 ft. long rock bolts: Elongation (per cent)	Tests on 8 ft. long rock bolts: Ultimate load (1,000 lb.)
1	Plain hollow core	To A.S. No. A 1	None	1.00	2.48	34,000	53,100	26	3	40.7
2	Deformed hollow core	To BS 970-1955 En5A	To A.S. No. A 92	0.925	2.31	33,000	52,800	28	6	46.5
3	Deformed hollow core	To A.S. No. A 1	To A.S. No. A.92	0.980	2.55	34,200	52,100	27	5	40.2
4	Continuously threaded B.S.W. 8 t.p.i. hollow core	To A.S. No. A 1	Cut threads	0.839	2.07	24,000*	41,000	9	9	40.1

* Brittle failure—No clear cut yield point.

TABLE V.

Results of "Pull-out" Tests on Lengths of Rock Bolt Shanks with Various Surface Treatments.
(One-inch nominal diameter—hollow core)

Surface treatment of shank	Embedment in grout (in.)	Grout 7 days old: Load at pull-out (lb.)	Grout 28 days old: Load at pull-out (lb.)	Grout 90 days old: Load at pull-out (lb.)	Nature of failure	Yield strength of the bar (lb.)
1. Plain bar (to A.S. No. A 1)	6 12 18 36	6,500 9,200 16,700 16,400	11,700 11,600 14,200 31,200	12,000 15,000 26,100 33,100	Shear at grout-steel interface.	34,000
2. Plain bar coated with wet epoxy resin	6 12 18	8,300 16,200 27,700	19,400 26,600 45,200	20,900 44,500 40,000	Shear in the grout or in the resin coating.	34,000
3. Plain bar coated with sand epoxy	6 12 18	32,000 43,400 48,400	39,200 48,600 52,200	45,500 49,500 49,300	Shear in grout at early ages & short embedments. Shear in resin at 90 days and long embedment.	34,000
4. Deformed bar hollow core (to BSS 970 En 5A) ASTM A 305 56T & A.S. No. A.92	6 12 18	24,000 39,800 46,000	39,200 49,600 49,800	37,700 44,000 45,400	Shear of a cylinder of grout at periphery of the deformations. Grout between the deformations broke up into flakes.	33,000
5. Deformed bar hollow core (to A.S. No. A.1)	6 12	23,800 37,000	No tests	No tests		34,200
6. Continuous thread BSW.8 t.p.i.	6 12 18	21,000 31,000 35,000	31,800 36,600 35,800	31,800 38,200 39,500	As Nos. 4 & 5 except that grout between threads was intact.	24,000

Tests the details of which are set out in Tables IV and V and Figs. 11 and 12 were carried out to ascertain the effects of various treatments of bar shank surface on the bond between the bar and cement grout.

The grout used for pull-out tests at 7 days and 28 days conformed to the standards for rock bolt grout set out in Section 4. (*g*): the average compression strength of 6-in. by 3-in. cylinders at 7, 28 and 90 days was 3,090, 5,080, and 7,300 lb./sq. in. respectively. For pull-out tests at 90 days, a somewhat weaker grout having an average strength of 5,730 lb./sq. in. at 90 days was used. The bars were grouted into steel tubes of $1\frac{3}{4}$ in. inside diameter and $\frac{1}{4}$ in. wall thickness. The pull-out tests were carried out in a vertical position with the grout tube uppermost.

The sand epoxy-coated bars (Ref. 17) were sand blasted and then brush-coated with resin. Sand passing No. 14 B.S. Sieve and retained on No. 25 B.S. Sieve was poured over the resin immediately afterwards and the coating then oven-cured.

The plain epoxy bars were embedded in grout within ten minutes of being coated as the pot-life of the resin used was only about 30 minutes.

The uncoated plain bars, the deformed bars, and the threaded bars were cleaned of factory grease with carbon tetrachloride and allowed to weather in the open at Cooma under summer conditions for three days.

The sand epoxy-coated bars had the highest bond strength, but the bond given by them is not sufficiently better than that of the deformed bars to warrant the greater cost of the epoxy process. Moreover, the deformed bars and the threaded bars are the only ones which, in grout 90 days old, showed no slippage within the working range of up to 20,000 lb. pull-out load (Fig. 12). Bars in grout 7 days old and 28 days old showed much greater slippage under load than those in grout 90 days old.

Deformed bar shanks are now usual for all bolts which are to be grouted. Generally, plain shank bolts are used only for

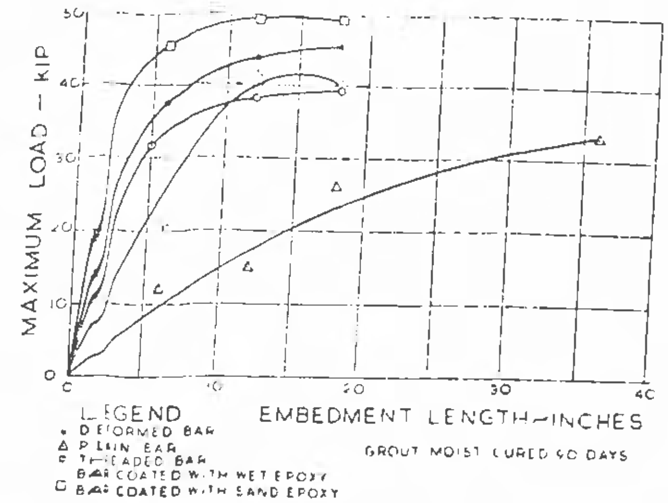

Fig. 11.—Pull-out Tests of Rock Bolt Shanks with Various Surface Treatments, in Neat Cement Grout—Pull-out Load v. Embedment Length

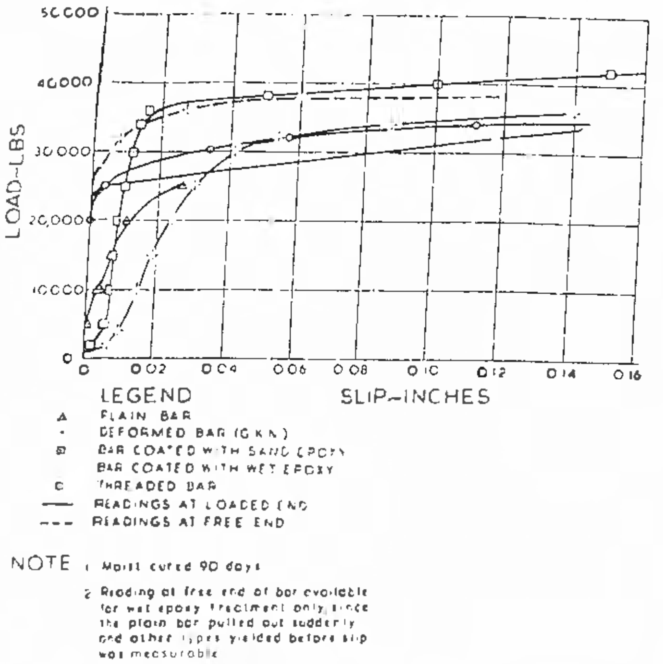

Fig. 12.—Pull-out Tests of Rock Bolt Shanks with Various Surface Treatments in Neat Cement Grout—Load v. Slip for 18-in. Embedment.

non-permanent works and in some cases for temporary support where, for reasons other than rock quality, a tunnel is to be fully lined with concrete.

4.—Rock Bolts and Rock Bolt Techniques on the Snowy Mountains Works.

4. (a) Types of Rock Bolt :

The essential components of a rock bolt are the shank, the anchorage and the bearing plate assembly. One type has an integral square bolt head, but in most cases both ends of the bolt are threaded and the bearing plate is held with a nut. The integral head type is not suitable for grouting. It is difficult to make it with a hollow core and, if an external deaeration tube is installed with the bolt, the tube frequently is wrapped around the bolt, when it is rotated to set the anchor. Another disadvantage is that pull-out tests cannot be done unless the bolt has been prepared during installation for such a test. Excluding the slot and wedge type, all other rock bolts are threaded at both ends.

Rock bolts are generally classified according to type of anchor, of which there are four groups : sliding wedge, sleeve and wedge, slot and wedge, and expansion shell.

The sliding wedge bolt is sometimes difficult to set in hard rock. In Tumut 1 Power Station, difficulty was also initially experienced in getting good anchorage in hard rock with slot and wedge bolts ; after a series of tests, a set of rules were successfully adopted (Ref. 3). Subsequently, these bolts were made groutable by attachment of grout and deaeration tubes of light metal. A disadvantage of slot and wedge bolts is that the hole depth must be accurate to within one inch.

As expansion shell anchors contact only the sides of the hole, the hole may be of any depth greater than the length of the bolt—which is a convenience in underground conditions. Some of them have the additional advantage that setting and tensioning can be done in one operation. They were used on Tumut 2 on ¾ in. dia. solid core shanks with external deaeration tubes. The deaeration tube, however, could not be attached to the shank before installation because the tube would become twisted around the shank during setting of the anchor. Moreover, expansion shells fill the hole so completely that the deaeration tube had to terminate on the underside of the anchor. Tumut 2 Power Station is the only project where ¾-in. bolts have been used and it is unlikely that they would be used again. The one-inch bolt offers greater strength in relation to the size of drill hole, and can have a hollow core which facilitates grouting.

4. (b) Rock Bolts and Anchors in Current Use :

On the Eucumbene-Snowy and Murray 1 Projects, currently under construction, all rock bolts which are to be grouted have 1 in. nominal diameter hollow core deformed shanks and expansion shell anchors. Many of the bolts are of steel to B.S. 970 : 1955, Grade En5A. The groutable bolts currently in use are shown in Fig. 13. The prototype of each of these anchors was designed by scaling up from anchors used with ¾-in. bolts, except that the drill hole diameter required was not increased in proportion. The result was that the metal in the anchor was under higher stress and in pull-out tests most of the prototypes failed at loads below the strength of the bolt shank. In conjunction with the manufacturers, changes in design and material were made until anchors were obtained which could withstand loads sufficient to break the shank.

For softer rocks, wedge and paired shell anchors have the advantage of a larger bearing area. They also work well in coarse-grained rock, but are sometimes difficult to set in hard fine-grained rock.

Wingshell quick-set anchors are more readily set than most bolts, because of the retaining spring. The shells, however, do not remain parallel during setting and, particularly in oversize holes in hard rock, the area on which bearing pressure is taken is small.

4. (c) Steel for Rock Bolts :

The choice of steel for rock bolts is a matter on which there are divided opinions. Most bolts used in the Authority's work are to A.S. No. A1—a plain mild steel. Medium tensile steel ¾-in. bolts of 37-ton steel have also been widely used. One of the bolts now being used is to B.S. 970 : 1955 Grade En5A, a 37-ton to 38-ton steel giving an ultimate strength in the shank of about 52,000 lb. A limited number of bolts made of old drill steels (55-ton steel) have also been used.

The disadvantage of using bolts of very high strength steel is that if the bolt did break, it would leave the hole with high velocity. In tests, drill steel bolts have been projected up to 125 ft. horizontally, and 25 to 30 ft. vertically. When, for special reasons, about 1,000 bolts of drill steel were used in the Tooma-Tumut tunnel, immediate grouting was stipulated as a precaution.

The cost of the steel in a rock bolt is a very small part of the cost of the bolt as finally installed. Use of higher strength steels

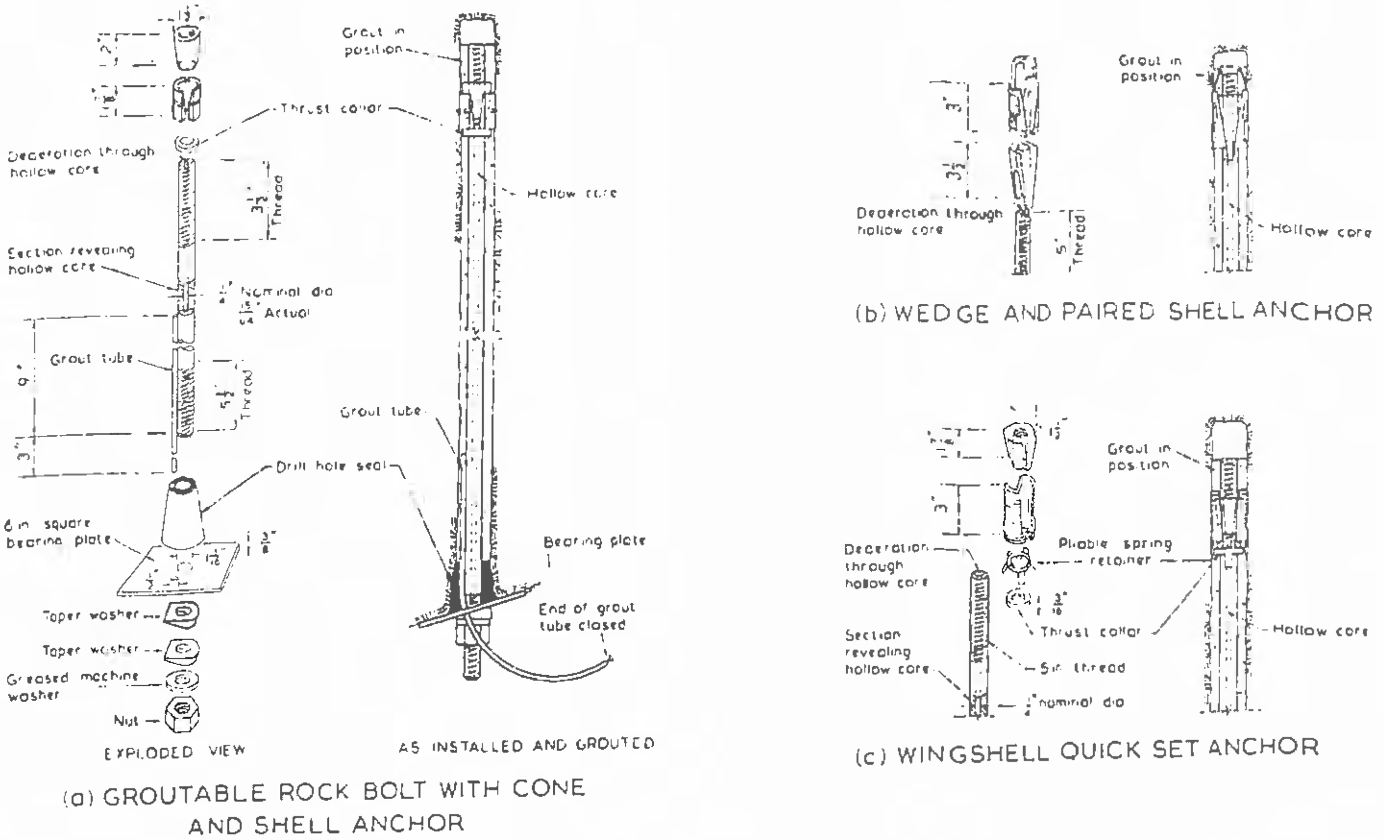

Fig. 13—Rock Bolts in Current Use in the Snowy Mountains Scheme.

could alleviate the difficulties described in 3. (c) and enable more support per bolt hole to be obtained.

The circumstances in which a bolt is likely to break are :—failure of the impact wrench to limit the torque it is applying to the bolt, heaving ground, or rock bursts in high-stress fields. The first risk might be overcome by closer surveillance of wrench maintenance and use of safety procedures. In heaving ground or where rock bursts are likely, mild steel bolts would be preferable.

4. (d) Bolt Shanks :

Elastically, the ideal shank shape would be one in which the cross-sectional area of the deformed section was equal to the area at the root of the threads. The present practice of machining off the deformations before rolling the thread automatically makes the threaded section the weakest part of the bolt and results in elongation at failure being largely concentrated in the threaded sections.

Continuously threaded bars have most of the advantages of deformed bars, but have a lower ultimate strength. Elongation under test of full size bolts is one and a half times that of other types of shank of the same steel, because it is not concentrated in short threaded ends. They also offer to small jobs the advantage that bar stock could be held on the job in long lengths and bolts cut off to required lengths as needed. If this type of bolt were used, rolled threads and a higher strength steel than A.S. No. A.1 would be desirable.

With regard to torque tension relationship, a current development in structural steelwork is of interest. Between the nut and the tip of the bolt a groove is machined in the bolt threads. A special wrench grips the bolt tip and the nut, and applies a differential torque between them. The reaction to the torque is taken partly by the nut and partly by the shank. When the torque between the nut and the bolt reaches the desired value, the tip of the bolt shears off and no further torque can be applied. The advantages of this system are that the torque in the bolt shank is reduced, the control of torque becomes part of the manufacturing process and the present necessity to check each bolt with a torque wrench could be eliminated. The existence of a bright end where the tip has broken off affords an easy check on the set of the bolt.

If this system were adopted, however, it would be necessary, if the present types of anchor were used, to have a left hand thread on the anchor end of the bolt.

4. (e) Rock Bolt Accessories :

All bolts in current use have, at the bearing plate end, a 1-in. B.S.W. thread 5½ in. long with a ⅞-in. B.S.W. hexagonal nut, tapped for a 1-in. thread, and a 6-in. by 6-in. by ⅜-in. mild steel bearing plate. Between the nut and the bearing plate, one machine washer and two taper (bevel) washers, to allow for rock face angularity, are provided as standard in pre-assembly of rock bolts prior to installation.

Sealing of the collar of the hole has always been a difficulty. The aim is that the seal be easy to apply, retain the grout u pressure, and not allow loss of tension in the bolt. Flat p of bitumen rubber latex joint filler gave seals only when the rock face was flat and the mouth of the hole smooth. Loss of tension always occurred in the bolt due to plastic flow of these seals where the original tightening up had failed to achieve a bearing plate-to-rock contact. The next step was to have the seal material in a container ring of shim metal 0.005 in. in thickness which, by preventing lateral spread of the seal material, enabled it to be pressed into the mouth of the hole as the bolt was tightened. This worked well in some cases, but failed when the mouth of the hole was irregular.

A seal of quick-setting mortar made up of one volume of sand, two of Portland cement, and one of a proprietary saturated solution of sodium carbonate in water glass was found very effective, although inconvenient for tunnel operations. It is mixed by kneading through the walls of a plastic bag for one minute and then rammed into place for two minutes. It sets in about four minutes at ordinary tunnel temperatures of 55°F. to 60°F., and is unaffected

by running water. This is still the only effective method in badly broken holes.

On Tumut 2 works, "dry-pack" mortar gave excellent results under dry conditions but was washed away where water was present.

Current commercial developments include tapered rubber seals. These give a good seal on only about half the holes and each seal has to be water pressure tested before grouting is commenced. If it does not hold pressure, a quick-setting mortar seal is applied.

On the Murrumbidgee-Eucumbene tunnel which was in quartzitic sandstone, indurated siltstone and slaty or phyllitic shales, it was found preferable to use only the quick-setting mortar seal. In the Snowy-Geehi tunnel and the Murray 1 Pressure Tunnel some of this mortar is regularly used to supplement the rubber seal.

One seal now under development consists of a truncated cone of polyurethane foam, partially impregnated with bitumen, and with holes for the bolt and the grout tube. If compressed or deformed, the seal returns only slowly to its normal shape and volume. The seal is compressed by hand, inserted in the hole and, in attempting to recover its normal volume, presses tightly enough against the rock to withstand grout pressures of up to 25 lb./sq. in.

In hollow core bolts, the hollow core is used as the deaeration tube: the grout injection tube is a 12-in. length of $\frac{1}{4}$ in. O.D., $\frac{3}{16}$ in. I.D. steel tube generally of the copper flash welded type.

4. (f) Installation Techniques:

For all bolts other than slot and wedge, the hole is usually drilled several inches longer than the bolt to avoid any chance of having to re-drill. As drill cuttings or sludge in the hole can prevent setting of the anchor, particularly with slot and wedge bolts, it is important that the holes be well cleaned out by a water or compressed air jet before the bolt is inserted. The bolts are held in racks on the jumbo completely assembled with anchor, bearing plate, two tapered washers, one machine washer and nut.

Before insertion, both the cone and shell and the wedge and paired shell anchors are adjusted to a neat sliding fit in the drill hole. Wingshell quick-setting anchors are adjusted so that the serrated edges of the shells are parallel.

Bolts with the cone and shell anchors and paired shell anchors are generally set by a first application of the impact wrench and tensioned by a second application. In the first, a drive nut is used. This has one end blanked off to prevent complete entry onto the bolt thread so that it is forced to spin the shank, thereby setting the anchor. Quick-set anchors require only one operation of the impact wrench, applied to the nut to set the anchor and tension the bolt. Wedge and paired shell anchors can also be set in this manner, if they are first given an initial set by hand turning the shank. This is usually done while the bolt is protruding about one foot. The bolt is then forced into the hole and the seal rammed firmly into place.

Where the hole mouth is too irregular for cone seals to be effective, the shank and anchor assembly are inserted into the hole and initial anchor set obtained by rotating or jerking the bolt shank. The bolt should then be at such a depth that about 2 in. of thread shows beyond the bearing plate in its final position. In the case of most expansion shell anchors, a quick-setting mortar seal is then applied, the bearing plate, washer and nut are assembled, and a torque of 250 lb. ft. is applied with the impact wrench to finally set the anchor and tension the bolt.

With cone and shell anchors, the anchor is given its final set with the drive nut and impact wrench before the quick-setting mortar seal is applied. Final assembly and tensioning follows. Ref. 18 gives completely detailed instructions for the installation of each type of bolt.

4. (g) Grout for Rock Bolts:

The principal properties required in rock bolt grouts are:

(i) "*Flowability*".—the grout must flow easily through grout hoses and grout tubes (the latter down to $\frac{3}{16}$ in. I.D.) under ordinary tunnel compressed air supply pressures of 85 to 100 lb./sq. in. A flow time of 25 to 30 seconds at 55°F. to 60°F. using the standard flow cone of 1,725 ml volume (Ref. 16) with a $\frac{1}{2}$ in. dia. orifice, indicates suitable flowability.

(ii) *Slight Expansion on Hardening*.—sufficient aluminium powder is added to the grout to offset settlement shrinkage. Excessive gas evolution results in loss of strength.

(iii) *High Shear Strength*.—to transfer load from the bolt, through the grout, to the rock.

These properties are obtained with grouts having water-cement ratios in the range 0.38 to 0.44 and to which commercial aluminium powder has been added in amounts up to about 0.005 per cent by weight of cement. They are mixed for three minutes with a triangular wire whisk driven by an electric drill at about 1,700 r.p.m. and strained through a No. 14 B.S. mesh screen to remove lumps.

The original requirement concerning fineness of the cement was that the specific surface should be not less than 4,500 sq. cm. per gm. Specific surface has been found to be a satisfactory means of checking different batches of the same brand of cement but not a reliable guide with another brand which may have a different particle size distribution. Some brands of cement which meet the specific surface requirement give grouts which, if of the required water-cement ratio of 0.38 to 0.44, will not pass through the flow cone at all; or require periods in excess of 40 seconds.

The amount of aluminium powder required was also found to vary widely with cement brands, and with different aluminium powders. Some cements require less than 0.002 per cent to achieve the required expansion of 0.1 to 0.2 in. per ft. of grout when placed in plastic tubes $1\frac{1}{2}$ in. dia. to a depth of two feet, at a temperature of 55°F. (approx. tunnel rock temperature). One cement showed no expansion even after 0.01 per cent of powder had been added.

Another variable with cement brand is the "pot life". Grouts made from some cements can be placed up to one hour after mixing without loss of expansion. With other cements, if the grout is placed after it is about three-quarters of an hour old, the expansion is insufficient to compensate for settlement shrinkage, especially if agitation has speeded up the loss of gas. It is found necessary to test each cement against a particular powder before deciding the amounts to be used.

Mistakes in measuring out the small amounts of aluminium powder required are avoided by the use of a calibrated and stamped measuring cup or scoop which, when filled in a standard manner, contains the correct weight for a bag of a particular type of cement.

While flowability and absence of settlement shrinkage are the first requirements in a rock bolt grout, strength is also important. Grouts which meet the first two requirements, however, usually give a strength of 4,000 lb./sq. in. on 6-in. by 3-in cylinders after curing for 28 days under standard conditions.

Many cements tested for rock bolt grout have shown abnormal stiffening within two minutes of mixing. Generally two minutes of high speed stirring will remove the effect, but other undesirable characteristics of abnormal stiffening—variable water requirements, variations in the expansion due to aluminium powder and surface cracking of test cylinders—are still present.

Specification requirements for a cement for rock bolt grout are:

(i) no *residue* on No 100 B.S Sieve,

(ii) a *flow time* of between 25 and 30 seconds through the standard flow cone (Ref 10) at a temperature between 55°F. and 60°F.,

(iii) the amount of *aluminium powder* necessary to obtain expansion, when the grout is cured at 55°F. to 60°F., to be not more than 0.005 per cent by weight of cement, for a grout of 0.38 to 0.44 water-cement ratio,

(iv) for minimum *compressive strength* to be 4,000 lb./sq. in on 6-in. by 3-in cylinders of 0.40 water-cement ratio grout, cured for 28 days at 70°F. to 72°F. and 95 to 100 per cent humidity,

(v) maximum variation in the *specific surface* of samples from individual batches of cement to be not more than 7 per cent different from the specific surface as nominated when the cement was approved for use, and

(vi) no symptoms of *false set*

4. (h) Grouting Procedure:

Although diaphragm and other positive displacement grout pumps have been tried out, grout hoppers of the type described in Ref. 15, of one-bag mix capacity, are now in universal use on Snowy Mountains works. It is interesting to note that a similar apparatus

was patented by Greathead in 1886 for injecting grout behind tunnel linings in London clay. Originally an air discharge was provided at the base of the hopper bowl to keep the grout agitated, but it has been found that if the grout has been mixed as set out above, air agitation while in the hopper is not necessary.

The grout is transferred to the hopper through a screen of No. 14 B.S. mesh. The grout hose is connected to the grout injection tube attached to the rock bolt, and air pressure is applied to the hopper. Normal practice is that, when grout flows freely from the hollow core, it is blocked with a wooden plug and pressure is allowed to build up in the drill hole for a few seconds. In ground where there is difficulty in getting a seal on the mouth of the hole, this step may be omitted. The metal grout tube is then closed with crimping pliers. The air pressure on the grout hopper is then momentarily released while the grout hose connection is transferred to the next rock bolt to be grouted.

In an unlined tunnel there is always the possibility that grout under pressure may produce disruptive interstitial pressures in the rock mass. In the early stages efforts were made to limit the grout pressure to no more than that required to fill the hole completely and the grout pressure was released immediately grout appeared at the mouth of the deaeration tube. However, over several years, there has been little evidence of this type of trouble. Present practice is to apply the full mains air pressure (85 to 100 lb./sq. in.) to the contents of the hopper. Where the rock is open jointed, the flow of grout into the joints from the hole is beneficial as a binding agent. In some cases grout flows from points in the rock surface adjacent to the hole. These leaks are caulked before completing the grouting of the bolt.

Grout blockages can be avoided by seeing that:

(i) the grout hopper and hose have no sudden changes of section all changes must be on long tapers,
(ii) there are no water leaks in the hopper and hose system,
(iii) there is three minutes of high speed mixing, and that
(iv) there is general cleanliness, in particular the screening of all grout through No. 14 B.S. mesh before charging into the hopper.

4. (i) *Protection of the Exposed Parts of Rock Bolts:*

The exposed parts of the rock bolt are soon contaminated by moisture, rock dust, and oily material. There is need for a coating which adheres well to damp, greasy, dusty or slightly rusty surfaces, is resistant to mechanical abrasion and offers a long-term protection during service in flowing water.

Bitumastic coatings were tried out but failed to adhere. Cement wash offers some advantages, but fails to adhere in the presence of grease or dirt. The most successful system has been cement grout over a proprietary brand of paint composed of gilsonite, a hardening synthetic resin, a petroleum solvent and flake aluminium. This was first used on the Murrumbidgee-Eucumbene tunnel (completed 1960). Bearing plate assemblies which had been primed with the paint and coated with cement grout were in excellent condition when inspected in 1962.

Bilge grease over gilsonite-aluminium paint has been found to give excellent lubrication and protection to the nut and bolt threads and the surfaces of washers. The paint is factory-applied to each component of the bearing plate assembly, including the bolt threads and four inches of the shank where it will pass through the seal. Only the nut threads are left uncoated. The bilge grease is then applied to the threads of the bolt and of the nut and to all surfaces of the washers. After completion of grouting, a ¼ in. thick layer of cement mortar is applied by brush to all parts of the bolt and bearing plate assembly that are accessible. Consideration is currently being given to use of galvanising as an alternative primer coat and the use of wax mastic as a lubricant and final coat.

4. (j) *Field and Laboratory Tests on Rock Bolts:*

After installation and again immediately prior to grouting, every bolt is checked with a calibrated hand torque wrench to ensure that the torque is 250 lb. ft.

When any doubt exists as to adequacy of general bolt installation practice at any particular place, pull-out tests may be carried out to ascertain the ultimate load capacity of typical bolt anchorages as installed. These are done with a 30-ton centre-hole hydraulic jack to apply and measure loads and a dial gauge of 0.001 in. accuracy to measure movements.

The actual tension in the bolt at any time may be measured if desired by applying a load to the exposed end of the bolt with this jack and reading off the load at which pressure of the nut on the bearing plate is relieved.

The usual arrangement for pull-out tests on installed bolts is to couple an auxiliary shank, which can pass through the centre hole of the jack, on to the bolt thread. An extension packer or chair, which has an opening wide enough to accommodate the coupling, is set up between the jack and the bearing plate. Taper plates are positioned below the chair to ensure alignment of the components. After positioning the jack on the chair and locating the system by screwing down a nut on the end of the auxiliary shank, a dial gauge is arranged to read relative movement between the end of the bolt and the body of the jack. Load is then applied by the jack, until either the anchor or the bolt fails.

On occasions the extent to which grout is filling the holes has been checked by diamond drilling out of a core containing the rock bolt.

The centre hole jack is also used for pull-out tests on new types of anchor submitted for approval and for checks on production lots. The anchors are mounted on standard hollow core bolts and set in drill holes made for the purpose. No chair is used as with this type of test the bolt can pass through the jack. A reference wire is installed in the hollow core and the elongation of the bolt measured by a dial gauge. A second gauge, usin[illegible] [illegible]e rock face as a reference, measures movement of the bolt as a [illegible] relative to the rock. If the anchor is satisfactory, the standard test bolt ultimately fails in the threads at 48,000 lb. pull.

Rock bolts can be used as stress measuring instruments. In Tumut 2 Power Station the relative movement between reference rods, inserted in the hollow cores, and the end of the bolt, enabled bolt loads to be computed and plotted against time to show changes in rock condition during power station excavation (Ref. 10). The bolts had been installed in the usual way but were grouted through external grout tubes.

The quality of rock bolts is checked by laboratory tests. Five bolts per 1,000 with a minimum of one from every consignment are laboratory tested. Where experience shows that satisfactory control of production is being maintained this may be reduced to two per thousand.

The tests commonly performed are:

(i) tensile test on the anchorage,
(ii) tensile test on the nut and bearing plate,
(iii) tensile test together with measurement of elongations, on the shank after machining off the deformations,
(iv) combined torque-tension tests on the nut and bearing plate end of the bolt to determine the torque-tension ratio and the shear stresses involved in tightening the nut.

Occasionally, solid round tensile test pieces are mach[illegible] from the bolt shanks and tested to ensure that test (iii) above [illegible] valid.

5.—The Use of Rock Bolts on the Works of the Snowy Mountains Authority.

5. (a) *General:*

The full benefits of rock bolts as the major means of support can be obtained only if the technical direction and the organization of work and equipment in the heading are set up for support by rock bolting.

At and near the face, decision regarding the manner and degree of support consists of two phases: immediate support after the blast, if needed, and a more general examination from time to time by the geologist who is primarily concerned with the general conditions over a length of tunnel, and with anticipation of the conditions which will be met in the next few rounds of excavation.

Where immediate support is in question, decision whether bolting is required and, if so, whether it is to be pattern or individual, is made partly from the rock structure as seen on the sides, roof and face and partly on an estimate of the nature of the rock which the next round will reveal. This is done while removal of the material brought down by the blast ("mucking out") is taking place. A further examination of the rock may be made when, at the conclusion of mucking out, the drill jumbo is moved up to the face and closer inspection of the roof and shoulders can be made from it. Bolt positions are marked on the rock with paint by the inspector.

Conditions at the face may often be difficult. It is practically impossible to get good lighting. A coating of dust rapidly collects on the rock, concealing open joints and soft seams. These circumstances frequently result in the installation of more rock bolts than may appear to be necessary on later inspection of clean rock surfaces under reasonably good lighting. For the same reasons under-bolting is also possible.

In addition to safety, full regard has to be paid to the need to ensure future permanency of the works. Broadly, this means "preventative bolting" at points which, at the time, offer no danger to personnel, but which require bolting to prevent later opening up or loosening. If the tunnel is not to be lined with concrete this is especially important.

When it is anticipated that poorer rock may be exposed by the next blast, adequate rock bolting up to the face will prevent overbreak on that round. If, however, the rock uncovered is better than was anticipated, the area in question may look over-bolted when viewed at a time when a wider exposure of the rock structures conditions can be examined.

The rock bolts are usually installed concurrently with the drilling of blast holes in the face for the next round. The bolt holes in the crown are generally drilled from the drilling jumbo using the top deck drifters. Middle deck drifters are used for rock bolt drilling below the shoulders, in the springing line area. Loosened rock below the springing line is generally considered to be a case for removal ("scaling" or "barring down") rather than rock bolting.

Rock bolting has sometimes been carried out from a separate jumbo intended to operate just behind the main face drilling jumbo. This is not satisfactory as the separate jumbo is often to be found hundreds of feet back from the face. It is fundamental that rock bolting should be carried out as an integral part of operations near the face. Current specifications require that the contractor shall so plan his equipment and operations that routine installation of rock bolts can be carried out within 35 ft. of the face, which, in effect, requires that it be done from the main jumbo. One of the early objections to bolting right up to the face was a belief that the bolts would almost certainly be damaged in the next blast. Experience is that this seldom occurs.

(b) Details of Application of Rock Bolting to Tumut 2 Pressure Tunnel:

The actual behaviour and support requirements of the rock in any particular case depend on factors such as tunnel size and shape, amount of explosives used, the nature of stress in the rock before excavation, the quantity and pressure of ground water and the orientation of the tunnel with respect to the main geological weaknesses, as well as on rock condition.

The bolting pattern at any particular point may be wholly determined by the nature of some local weakness. How the bolting is planned can best be described by taking a particular example. Tumut 2 Pressure Tunnel, which was 23 ft. in diameter as excavated, will be used. In this tunnel, the rock encountered was generally of fairly uniform condition, Class 4 predominating, with small amounts of Classes 3 and 5 of Table III.

In general, Class 5 was unsupported. Class 4 was either unsupported or partly supported by rock bolts, and Class 3 required either "complete" support in the roof by means of rock bolts, or light steel support. Differences in the support installed within any particular rock class were, in most cases, due to the effects of orientation of geological weaknesses in relation to the tunnel surfaces. Fig. 14 illustrates the most common weakness and Fig. 15 the pattern of rock bolting adopted. More detailed geological information is given in Ref. 19.

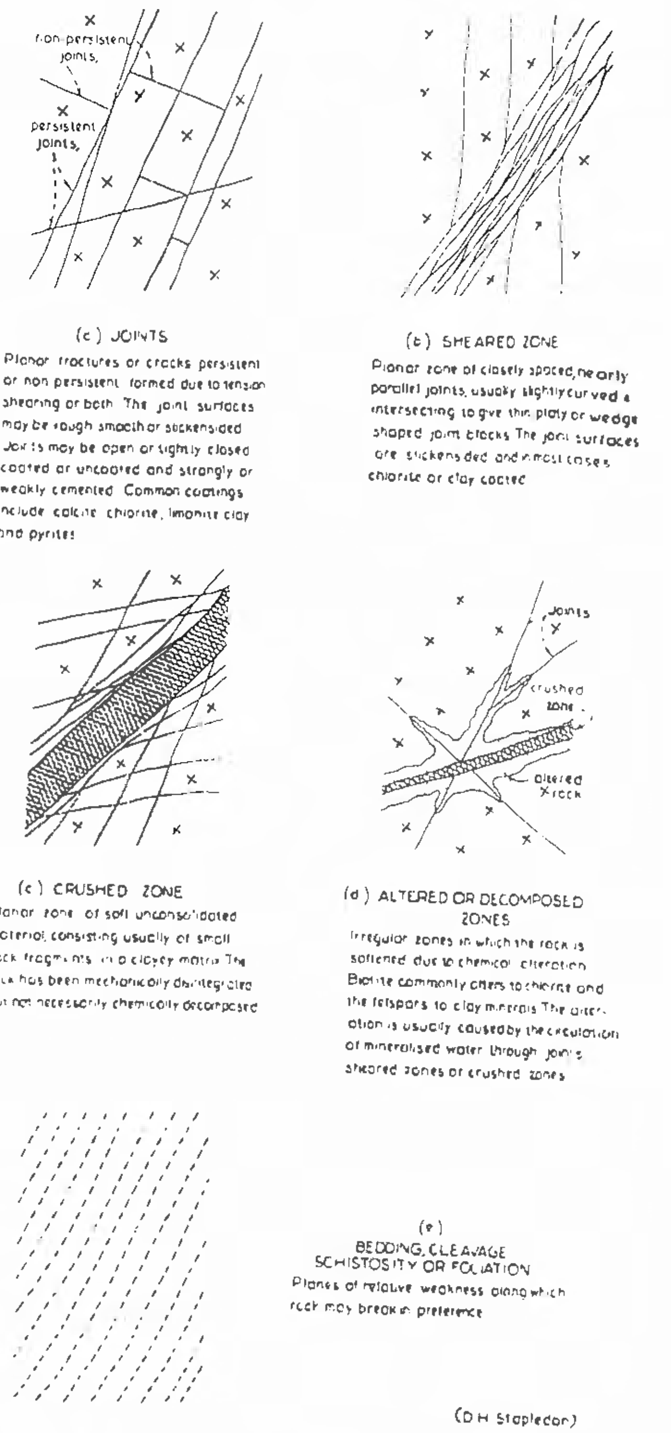

Fig 14.—Common Weaknesses in Unweathered Hard Rock

(i) "Partial" Support of Class 4 Rock.—Partial support or "pinning" by rock bolts is illustrated in Fig. 15. The bolts were spaced from 4 ft. to 10 ft. apart longitudinally in the shoulder or roof where required. Where used in this way, and installed within 3 ft. to 5 ft. of the face, rock bolts proved very effective in controlling "progressive" overbreak due to joints or soft seams oriented almost parallel to one of the tunnel surfaces. This is the case with the flat-lying joint shown in the longitudinal section in Fig. 15.

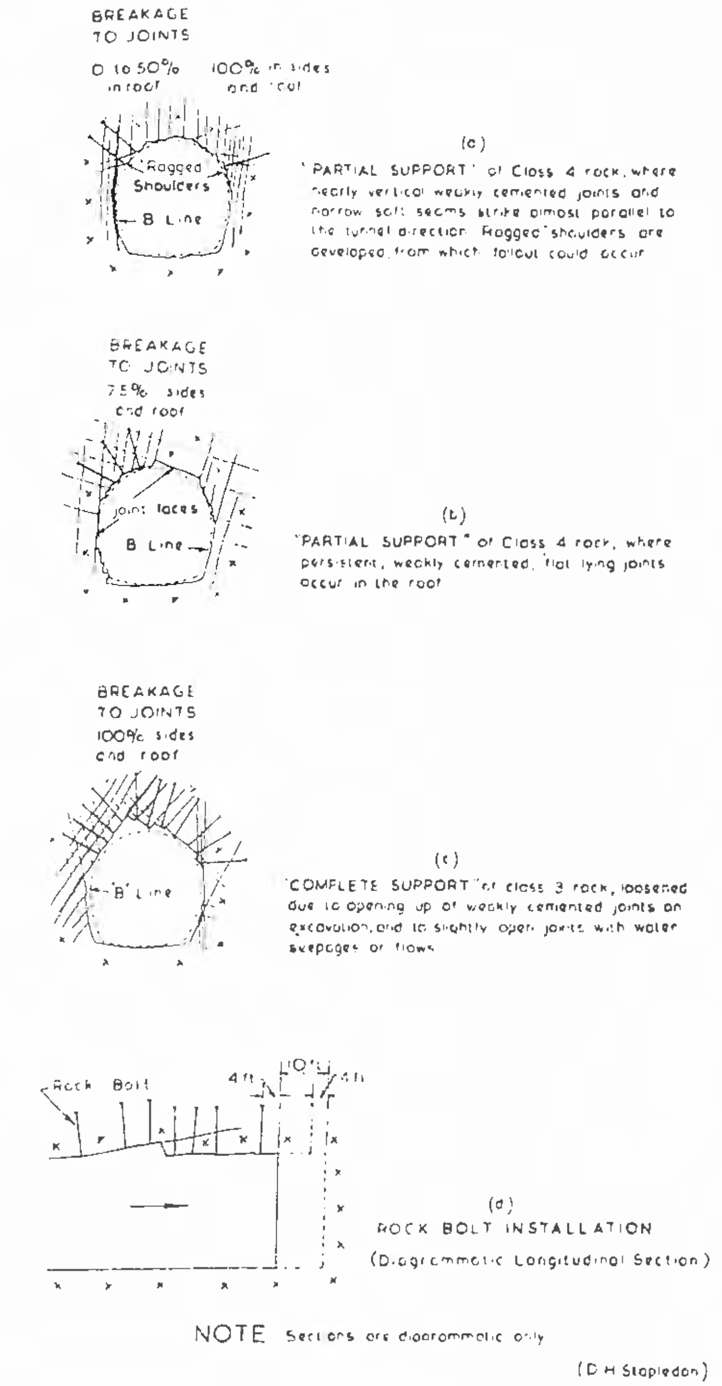

Fig. 15 — Tumut 2 Pressure Tunnel Typical Rock Bolt Installations.

At many points "shoulder pinning", that is, bolting only at and just above the "shoulders", was used. In some of these areas joints and soft seams continued to open up for some days after blasting, notwithstanding the bolting, but there was little or no fall-out.

In general, no regard was taken of the possibility of unseen weaknesses or conditions when determining the amount of bolting. While some risk was possibly incurred by this practice, attempts to cover the unknown and invisible would have resulted in the use of several times as many bolts as were actually needed and used.

(ii) **"Complete" Support of Class 3 Rock.** In the rock of Class 3, Class 3 to 4 or Class 4 to 3, rock bolting to within 4 ft. of the working face proved particularly successful. While some steel supports were used in every section judged to be Class 3, considerable lengths of tunnel of the 4 to 3 and the 3 to 4 Classes were supported by rock bolts only. Some of the Class 3 rock itself was supported by bolts only. In the rock approaching Class 3, rock bolting achieved good control of overbreak and roof stability. Had rock bolting not been available, many more steel sets would have been used and there would have been fall-outs in marginal places not poor enough to warrant steel sets being installed.

Fig. 15 is typical of sections of rock-bolted tunnel in which the rock conditions approached Class 3. Although the bolt lengths are 10 ft., they were installed at spacings as low as 2½ ft., because of the small size and looseness of the blocks. This pattern of bolting is designed more for prevention of local falls than for overall support.

If overall support had been the objective, 7-ft. bolts at 3-ft. spacing might well have been used. In similar rock in another tunnel this latter pattern was used successfully in openings up to 28 ft. wide and 35 ft. high—a case of an exception to the general rule given in 3 (*a*).

(iii) **Large Joint Faces.**—Where a large joint face occurred in the roof or walls, as at (*a*) in Fig. 14 and (*b*) in Fig. 15, it was usual to put several bolts into it, on the assumption that there were other parallel joints behind it, unless it could be determined from adjacent rock exposures that such was unlikely. When viewed later, these areas sometimes appeared to have been over-bolted.

(iv) **Deterioration after Excavation.**—A point of some concern was the avoidance of "fallouts" or other deterioration of rock in the period between the time of excavation and tim[illegible] lining. In Tumut 2 Pressure Tunnel, no deterioration in co[illegible]tion occurred in Class 5 rock. At some points in Class 4 and Class 3 rock, the blast had caused considerable opening up of joints in the zone near the tunnel surface. As much as possible of the loose material was removed before rock bolting. In some places mortar patches ("telltales"), were placed across suspect joints to reveal any opening up of the joint.

In the Class 3 and 4 rock, "slabbing off" occurred in the unbolted wall below the springing line. Having regard to the stress distributions referred to earlier, it is necessary to consider where this might have been promoted by the existence of a strongly bolted area in the shoulders. In Tumut 2 Pressure Tunnel, however, it is believed to have been due to the inherently loose nature of the rock which was such that little improvement would have been achieved by further barring down. There were some falls of blocks, generally less than one cu. ft., from the roof. Perhaps the bars used for scaling down were too light; they were ¾ in. water pipe, up to 20 ft. long, with short tips of tool steel.

5. (c) *Rock Bolting on Other Recent Upper Tumut Works:*

Concurrently with the Tumut 2 Project, work was proceeding on the Murrumbidgee-Eucumbene and the Tooma-Tumut Tunnel.

On the Murrumbidgee-Eucumbene tunnel, which was 12 in diameter, rock bolts were installed from the rear of the drill jumbo (Fig. 16) within about 16 ft. of the face. Side flaps were provided on the jumbo at the rock bolting station and either a mounting bar for drifters was installed or 2 ft. extensions were made to the stoper air legs. Using two stopers or drifters, a crew of three could install all bolts required during the time taken to drill the face for the next round. If it was necessary to bolt right up to the face ("forward bolting"), the three-man team could achieve this without appreciable delay to the next firing of the face. The usual length of bolt was 8 ft. Six-day world tunnelling records of 532 ft., 563 ft., and 590 ft. were made on this tunnel while it was being bolted with alternatively three bolts and five bolts each at 5 ft. spacings for about 30 per cent of the length.

In the Tooma-Tumut Tunnel, which was 13 ft. horseshoe, the normal pattern was four to six bolts, each 8 ft. long, although occasionally 10 ft. bolts were used. The design of the main jumbos used on this project did not allow of their being fitted with satisfactory permanent drilling equipment for rock bolt work. Bolting was carried out from the main jumbo deck only when it

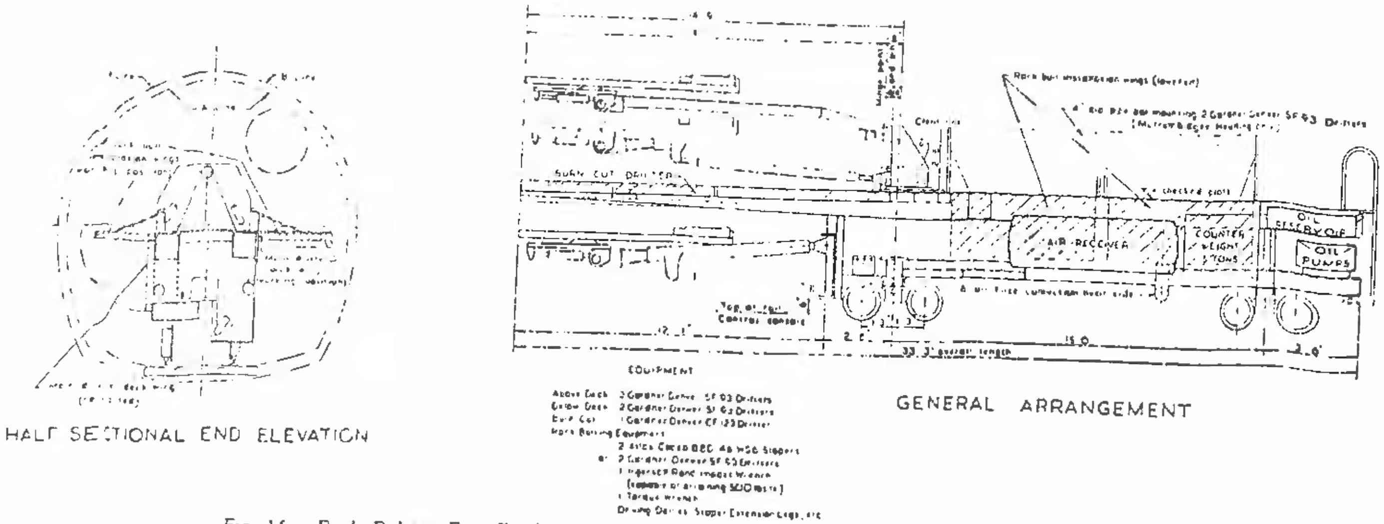

Fig 16.—Rock Bolting Face Jumbo for 12 ft dia Tunnel, Murrumbidgee-Eucumbene Tunnel, 1959.

was necessary to forward bolt, which was done with air leg drills during drilling of the face. In exceptional cases, work on the face was suspended until enough bolts had been placed in the roof.

Most of the bolts in this tunnel were installed from separate jumbos specifically designed for rock bolting. Each main heading had one jumbo fitted with two, and sometimes three, Gardner Denver CF89 drifters with power-feeds. The bolting was carried out at varying distances from the face and generally took place on the night shift or on Sundays to avoid interference to main track operations. Although marginal ground was always bolted up to the face, there was difficulty in keeping the general bolting operations from the separate rock bolt jumbo as close to the face as desired.

5. (d) Rock Bolting on Current Works:

On the Eucumbene-Snowy and the Snowy-Geehi works at present under construction, full advantage has been taken of experience on the works previously mentioned.

Excavation of one tunnel, the 1,094 ft. long diversion tunnel for Geehi Dam, was completed in October, 1962. This is of 21 ft. dia. and like most diversion tunnels is partly in weathered material. A number of small sheared zones and open limonite stained joints intersect the tunnel at an acute angle. 552 ft. of the tunnel was supported by steel sets and 380 ft. by rock bolts; 162 ft. did not require any support.

The Snowy-Geehi tunnel of 21 ft. nominal diameter and the Murray 1 Pressure Tunnel of 24 ft. nominal diameter are currently being excavated. The jumbos used on these have two rock bolt drifters on the front end which are mounted on chain drive slides by which they can be brought into any position between the front of the jumbo and slightly rear of its midpoint. These are used when forward bolting is required. Two rock bolt drifters are similarly mounted on the rear half of the jumbo and are the ones used for all normal bolting. An additional feature of this jumbo is that the face drifter mountings were designed so that it would be possible, if desired, to direct them against the crown and the shoulders, sections of the jumbo decks being removable.

When using the rear drifters only, up to 18 bolts per round have been placed without any loss of rate of advance. The most used pattern on these tunnels is 5 to 8 bolts 8 ft. or 10 ft. in length with a pattern spacing of 4 ft. or 5 ft.

On the 21 ft. nominal diameter Eucumbene-Snowy Tunnel, of which by mid-October, 1962, approximately 20,000 ft. had been driven on three headings, bolts are installed from a rock bolting platform on the main jumbo behind the face drifters. Normal installation of rock bolts is at 22 to 35 ft. from the face—that is, of the order of 1 to 1½ diameters of the tunnel. Forward bolting is done by stopers working from the decks of the jumbo. The most frequent pattern is five to eight bolts with a pattern spacing of 4 ft. Typical rounds are 12 ft. so that there is a maximum of 24 bolts to be installed per round.

In the Island Bend heading of this tunnel, some 4,100 bolts were installed in the first mile. Of these 6 per cent were forward bolting. In every case, on this tunnel where forward bolting has been used, it has proved possible to avoid use of steel sets.

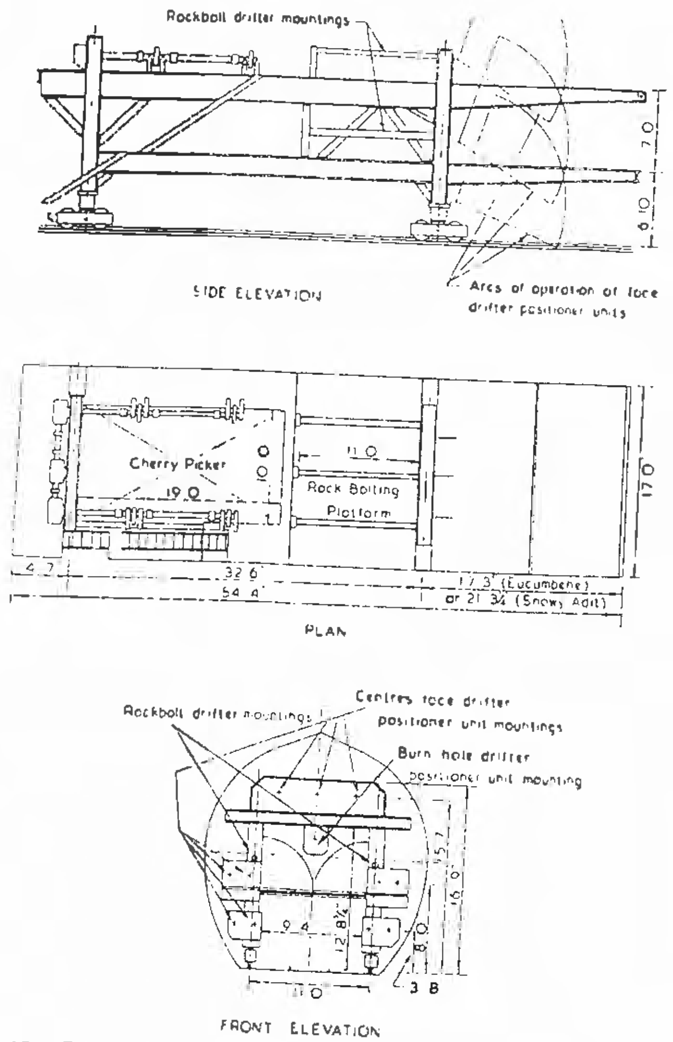

Fig 17.—Rock Bolting Face Jumbo for 21 ft. dia Eucumbene-Snowy Tunnel, 1962.

All necessary bolts are installed, tensioned and tested before the next firing of the face. After testing each bolt the inspector places a metal tag on it and plots its position on a diagram on his shift report.

Fig. 17 shows the jumbo used on this tunnel. Originally four rock bolting drifters with 6-ft slides were mounted on the top middle deck in the section 22 ft to 33 ft. from the front end. This proved unsatisfactory. The arrangement shown in Fig 17 proved satisfactory. One drifter is operated from each of the three bars on the top deck and, for bolting at or below the shoulders, from the two bars on the middle deck.

As in the Murrumbidgee-Eucumbene Tunnel the influence of rock bolting in improving the rate of advance has again been demonstrated. On the Island Bend heading in granite the following daily advances have been obtained.—

(i) Bolting from the normal position on the jumbo—49 9 ft per day,
(ii) Forward bolting—36 3 ft per day,
(iii) While placing 6-in x 5-in R S J sets at 5-ft spacings—24 5 ft. per day.

Normal rock bolting thus allowed of twice the rate of advance obtained when using light steel sets.

Acknowledgments.

The developments reported in the paper were the composite work of many engineers, geologists and other technical staff engaged on underground excavations and investigations associated with it, and individual contributions were too numerous to mention. The contributions and co-operation of the Authority's major contractors and of the principal rock bolt manufacturers is also acknowledged.

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Discussion

Mr. G. T. Colebatch (Member), **Mr. L. A. Endersbee (Member) and Mr. H. L. Paxton** (Associate Member) (Tasmania Division).—

Introduction :

We regard this paper as one of great practical value to anyone connected with investigation, design or construction of underground works in rock material. Over the past decade permanent rock bolting has proved to be a major factor, in underground excavation in improving the safety and efficiency of rock removal and in reducing the cost thereof significantly.

This is one of several publications on rock bolting by Snowy Mountains Hydro-Electric Authority authors, and brings us virtually up to date on current practice by the Authority. The authors are to be commended for a most valuable contribution.

Naturally, the techniques developed, the results obtained and the deductions made are based on experience in the class of rock found in the Snowy Mountains area. This is basically hard rock with its condition varying widely as indicated in Table III of the paper.

In Tasmania, the Hydro-Electric Commission has had experience recently in sedimentary rocks and has developed suitable techniques and equipment for this softer material.

Use of Permanent Rock Bolts by the Hydro-Electric Commission, Tasmania :

The Commission has used rock bolts for underground support since 1955, and in the present Great Lake Power Development their use for permanent support has been extensive. The following table shows that about 35,000 grouted rock bolts were used including approximately 9,000 in the underground power station.

Location of Usage	*Number of Bolts*	*Remarks*
Poatina Power Station (300 ft. × 45 ft × 85 ft)	9,143	Grouted
Access shaft (27 ft. × 14 ft)	1,847	,,
Access tunnel (18 ft. dia)	2,888	,,
Tailrace tunnel (16 ft -1 in. dia)	12,648	,,
Penstock tunnel (12 ft.-6 in dia)	2,987	Non-groutable
Headrace tunnel (19 ft. and 16 ft -2 in. dia)	8,109	Both types used
	37,622	

The standard length of rock bolt used for general tunnel support has been 8 ft. In the power station roof and walls where an extensive zone of unstressed rock was expected the lengths varied up to 16 ft. with the majority 12 ft. (Some 6-ft. bolts have been used for temporary support but were not grouted.)

From our experience, we agree with most of the statements in the paper. However, we do differ on some aspects on which we comment below, referring to the Section concerned of the paper under discussion.

Types of Rock Bolt (Section 4(*a*)) :

(a) **Anchors.**—The Commission has made tests on a number of the types of anchor now on the market and investigated the merits of others. However, all the rock bolts put in during routine installations have been of the slot and wedge type (high tensile expanding shell types at Catagunya and Arthurs Lakes Power Stations).

Some jacking tests made have shown that this type of anchor is capable of developing the full tensile strength of the bolts. Of probably more significance is the fact that virtually no rock bolts installed have shown any signs of anchor slip when accepting the tension applied by the nut at a torque of 250 lb. ft. (This is the same torque as used by S.M.H.E.A.)

Anchorage has been equally successful in dolerite, in the hard permian mudstones of the Great Lake Power Station and tailrace, and in the softer Triassic sedimentary rocks of the Great Lake penstock and headrace tunnels.

In terms of direct cost the slot and wedge type is substantially cheaper than any other type of rock anchor on the market.

In terms of cost of installation the Commission would contend that this type of anchor is not inferior to any other. It has only two parts and is easily and quickly assembled, and its assembly is unlikely to become ineffective through damage when being inserted in the drill hole. The final driving of the bolt on to the wedge is a matter of seconds with standard equipment.

We have not found much difficulty due to the disadvantage mentioned in the paper that the hole must be drilled to an accurate depth. For all routine work a drill steel has been used of such a length that if the drill is run until the chuck reaches the rock the bolt can be directly installed and will stand out from the rock by the requisite amount.

The slot and wedge type of anchor is suitable for use as a groutable type as the de-aeration tube can be carried past the anchor. This ensures that the anchor as well as the shank of the bolt is encased in grout. There is also the advantage that the bolt does not have to be rotated in the hole during installation which can be a cause of damage to the tube.

One batch of bolts supplied with tubes attached by the makers was unsuitable because the tubes were located so that their ends were crushed when the wedge was driven into the bolt. If the tube is on the line of the slot this damage does not occur. Our present practice is to buy the bolts and tubes separately and make up our own assemblies so this point can be attended to satisfactorily.

(b) **Bolts** (Section 4(*b*)).—For all routine work the Commission is using plain round mild steel rod with a nominal diameter for the rolled thread of 1 in. Actual diameter of the rod averages 0.92 in.

The Commission had, at one time, to ensure that when ground movements occurred in the roof of the power station the bolts did not become elongated to the point of failure. To this end tests were made on the standard rock bolts in use. It was established that yield point was at a load of 11 tons (37,500 lb./sq. in. for the diameter of bolt used). The load at failure ranged between 17 and 21 tons, and elongation was a minimum of about 5¾ in. on a 6-ft. bolt.

All bolts ultimately failed by necking in one or both of the legs of the slot.

(c) **Washers and Nuts** (Section 4(*e*)).—Bearing plates 6 in. × 6 in. made from ⅜-in. mild steel plate with a separate hole for the grout tubes, with appropriate tapered or flat washers and mild steel nuts, are being used. These are thought to be identical with those in use by the S.M.H.E.A.

(d) **Grout Tubes.**—Trouble was experienced due to grout tubes being damaged in handling if the bolts were transported from the factory with tubes attached. For this reason, and to ensure the correct placing of the tubes as mentioned above, the Commission purchases the bolts and the tubes separately and makes up the whole assembly on site by taping the tubes to the bolts.

The use of hollow steel rods in place of grout tubes cannot be justified by the Commission on the ground of costs.

(e) **Sealing of Holes before Grouting** (Section 4(*f*)).—So far as is known, the Commission was the first user of rubber plugs for this purpose. These were made up, to its own specification, with a central hole for the bolt and two holes adjacent for the grout tubes. Only in rare cases is it impossible to seal a hole satisfactorily with such plugs. If the rock under the bearing plate is broken and uneven a short length of pipe is used as a spacer between the rubber plug and the plate to force the plug into a sound part of the drill hole.

Grouting of Rock Bolts (Section 4(*g*)) :

Practice would be generally similar to that employed by S.M.H.E.A. except for the use of aluminium powder. This was initially used, but after a grouted bolt and its surrounding rock had been drilled out as a large diameter diamond drill core and closely examined, the use of aluminium powder was discontinued. It was found that the grout used had developed a spongy and powdery condition lacking strength and bond to either the bolt or the rock. The quality of the grout deteriorated as it went up the hole, suggesting that there had been a rising of hydrogen bubbles from the aluminium until they reached a concentration that impaired the grout. Did the authors carry out tests to ensure that loss of strength was not serious as a result of the addition of aluminium powder ?

Bond to Bolts and Rock (Section 3(*f*)) :

When the bolt mentioned above was examined the bond strength was not high either between the rod and the grout or between the grout and the rock. Further, it was evident that if load caused elongation of the bolt with consequent reduction of diameter the bond would be broken.

It would appear that too much reliance should not be placed on bond, and that the use of deformed bar is of doubtful value unless a very good grout-to-rock bond can also be ensured. Were tests of bond carried out by S.M.H.E.A. particularly where aluminium powder was added ?

Protection from Corrosion (Section 4(*j*)) :

Generally, where rock bolts have been used for permanent support, a steel mesh has also been used to prevent fall-out between bolts, and the whole has finally been gunited. This should give complete and permanent protection to the exterior parts of the bolts from corrosion, and no steps to paint or coat the parts have been taken.

Practical consideration in Rock Bolt Placing (Sections 2(*d*) and 5) :

The Commission would not be in complete agreement with the S.M.H.E.A. on some points mentioned, particularly the statement that rock bolting can be nearly always carried out without appreciable interruption to other work in a tunnel. It appears that generally, with the Authority, the bolts have been installed off the back of the drilling jumbo or even further back in the tunnel. Where "forward bolting" is mentioned this seems to have been carried out over men working below. It seems from this that bolting has not generally been carried out in ground that was considered dangerous or failing, and was, in fact, mainly used in ground which was at the time standing satisfactorily without any support and which might well have continued so to stand indefinitely. It was, then, presumably a precaution against long term failure. The Commission has at times used rock bolts for support of ground, right against the face, both in sandstone and dolerite tunnels, *where adequate support was essential before any other work below the area could be contemplated.* Under these circumstances, the drill jumbo may well be tied up, whilst two or three men only with not more than one machine, and using the greatest care, insert the requisite number of bolts and mesh. This is usually a cheaper process than standing steel sets, but it may well be a slower one.

Under such circumstances, too, it is possible that morale would be better under sets than under rock bolts.

Perhaps the authors would comment on whether in fact much forward bolting was carried out under dangerous conditions.

One difficulty which has been experienced by the Commission is in the transition from no support, to rock bolts, to sets, and vice versa. This difficulty is due to the decisions made to vary tunnel diameters with variations in the final lining adopted. On one occasion the Commission commenced to drive a tunnel of diameter 19 ft. in dolerite. It was expected that it would be largely unsupported and unlined but certain sections of poor rock needed support and rock bolts were installed. As worse ground was later encountered it became necessary to stand sets and to design a full concrete lining. It then became essential to strip areas, already bolted, to a diameter of 20 ft. 6 in. so that sets should not protrude too far into the lining. Stripping of an area which has already been bolted was found to be a slow, difficult and often dangerous proceeding.

In the above circumstances, the early adoption of rock bolting was disadvantageous.

Steel Sets and Rock Bolts Combined:

A practice used in the Commission, which is not covered in the paper, is that of adopting steel sets in conjunction with grouted rock bolts. This system is most applicable to tunnels which have been bored to a smooth perimeter. Long lengths of the Poatina tailrace tunnel, bored to a diameter of approximately 16 ft. by the "Mole" have been supported by sections of light steel sets covering from 90 to 180 degrees of the back which are themselves supported by rock bolts at the crown and springing line. In this way the support of a small number of rock bolts can be distributed over a larger area (see Fig. *D1*). This proved to be quicker and more satisfactory than rock bolts alone.

Fig. D1.—Poatina Tailrace Tunnel showing Light Steel Sets and Steel Mesh in a Tunnel excavated by the Mole.

Lagging between Rock Bolts (Section 2(*d*)):

The paper makes only passing reference to the necessity of holding and supporting rock between the pattern of bolts. This is probably because the hard granitic rocks of the Snowy area are less liable to slab away in small pieces than are sedimentary rocks. The Commission has found that properly proportioned wire mesh is an essential and extremely effective adjunct to rock bolting. If possible it should be placed under the plate washers of the bolts at the time the bolts are installed. This may not be possible if bolting is being carried out close to a face which is being blasted, as the flyrock will damage the mesh. If it has to be placed later then there is either the alternative of slacking off the nut and removing the washer if the ground appears to be capable of standing while the tension is off the bolt, or of placing a second washer and nut on top of the first.

Failure of Rock Bolting:

The Commission has had only one failure of rock which had been bolted. This occurred in the Great Lake penstock tunnel in Triassic sandstone, when some 100 ft. length of the back of the tunnel collapsed about a month after excavation, bringing with it the majority of the bolts. These bolts were mainly 6 ft. long and had not been anchored far enough back in the rock for the conditions found to exist. It appears that if the rock is soft and liable to crumble between the bolts little reliance can be placed on them to create an effective "beam" of rock to span an opening, and that they must then be anchored far enough back into the country for the anchorages to be substantially outside the zone influenced by the tunnel.

Use of Mesh Pins (Fig. *D2*):

Although perhaps not strictly relevant to the paper, brief mention is made to the mesh pins developed by the Commission as a useful adjunct to tunnel support by bolts. These are now used extensively where it is desired to hold mesh to a rock face, but where the full strength of a standard rock bolt is not required.

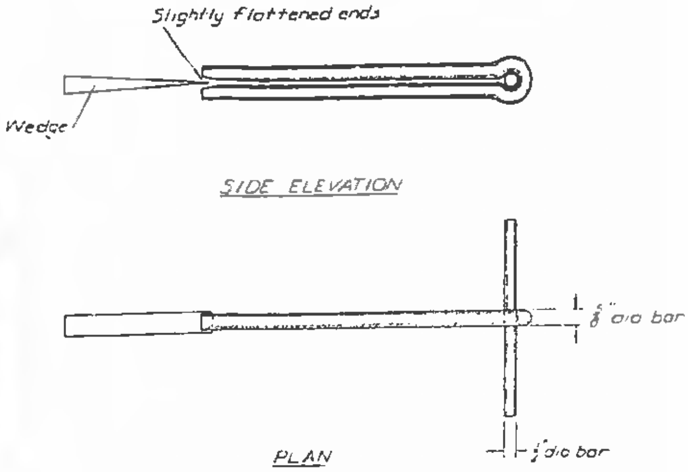


Fig D2.—Mesh Pins

They are formed by bending a length of ⅜ in. dia. reinforcing bar, which has had its ends slightly flattened, into a hairpin round a second short length of bar which forms a head. They are set in the rock by expanding the pin in a drill hole over a standard rock bolt wedge.

The head picks up two or three wires of mesh and adeq[illegible] supports the mesh between bolts.

Costs (Section 2(*d*)):

The paper gives no direct indication of the costs of placing bolts. This would have been of interest and value. The Commission's average field cost for placing an 8-ft. bolt is of the order of £3 15s. 0d. to £4 0s. 0d. This includes the cost of the bolt, wedge, washer, nut, etc., all drilling charges, cost of grout, and all labour. These are costs for regular routine installation which forms part of a planned operation Emergency bolting during tunnelling operations is almost always more expensive and often causes costly delays to other phases of the work.

Some estimates are given in the paper of the very substantial savings which can be made where rock bolts are used in lieu of steel sets in tunnels. Thus, for a 21 ft. dia. tunnel, the increase in *quantity* of "pay" concrete with steel sets as compared with rock bolts is given as about 40 per cent. One would expect that the actual *concrete cost* increase would be less than this unless, under

contract tendering, the price per cubic yard remained constant. The increase in *total tunnel costs*—including excavation—would presumably be not much more than 20 per cent.

Yet, in a further statement, the authors say that in fully lined tunnels the effect of using light steel set support in lieu of rock bolts *is to increase the total cost per foot by some 45 per cent.* This statement would appear to be at variance with the first statement and we would appreciate the authors' comments

Uses of Permanent Rock Bolts by the H.E.C., Tasmania :

The following is a list of uses of permanent rock bolts which may be of interest.—

(1) Tunnel support.
(2) Complete support for the Poatina Underground Power Station excavation, walls, floor and roof
(3) Support for the top floor of the Poatina Power Station This floor is hung off beams rock-bolted to the roof
(4) Attaching brackets to walls and tying down crane columns.
(5) Increasing the dead weight of Catagunya Power Station and Arthurs Lakes Pump Station against uplift.
(6) Measuring bolts, recording dilation of the rock between anchorage and exposed end
(7) The only means of support of the crane beams of a 5-ton overhead construction crane
(8) Giving extra support for the penstock anchors on the sandstone cliffs at Poatina, etc.
(9) Hold down, for transmission line towers, Meadowbank Switchyard (soft sandstone)
(10) At Arthurs Lakes Pumping Station and at an anchor of Poatina penstock and grouted rock bolts reduced excavation considerably.

Note Items 3 to 10 do not refer to underground work

Concluding Remarks :

The paper demonstrates clearly the need for a scientific approach in the design and installation of rock support in underground works and the advisability of very close liaison between the engineer and the geologist on the site. There is a great deal still to learn about the structural mechanics of natural rocks. The behaviour of rock at the periphery of a tunnel blasted out by explosives is not easily predictable, but the authors have contributed greatly to the practical solution of this problem. It is essential to find out as much as possible, before placing support, regarding the detailed geology, the stresses which exist, water pressure, creep and so on.

We hope the day is not too far off when a breakthrough will occur in tunnel boring and mechanical machines, such as the "Mole", or that other methods will be evolved which will, at an economical rate, give us a smooth bored tunnel in hard rock with virtually no shattering at the periphery, as no explosives are used In these happy circumstances, far fewer bolts should be required very fair rock (Class 3 by the authors) than in conventionally driven nel. On the other hand in Class 2 rock steel sets may be re-ced to a greater degree by rock bolts than is normal at present.

The important thing is that all these engineering improvements are definitely resulting in faster tunnelling and in keeping the unit cost down while other costs are gradually rising.

We consider that it should be realized that conclusions reached in the use of bolts in one class of rock should not be adopted for a different class of rock without careful investigation and testing.

We hope, finally, that the S.M.H.E.A. will continue tunnelling, will continue their research and will continue to keep others so well informed of the results obtained.

Mr. J. F. Chappell (Associate Member, Tasmania Division).—Mr. Pender has indicated that the rock bolts when grouted have a very long life, possibly as long as 2,000 years. In view of the very often unsatisfactory results obtained in the grouting of prestressed concrete cables could he give us more information about the effectiveness of the grouting process and particularly any results of the tests which have been made. I feel that the conditions for obtaining a good result are severe, especially considering the small space remaining around the bolt and also that the holes will probably not be exactly straight, thus causing the bolt to contact the sides of the hole quite often and thus preventing a covering of grout to the bolt at this point.

Mr. H. C. V. Woollard (Associate Member, Tasmania Division).—The authors are to be complimented on a very useful paper which brings up to date information presented earlier on the development and very effective use of rock bolting by the Snowy Mountains Authority. This information has, of course, been applied with advantage elsewhere, although modifications have naturally been necessary to meet varying conditions. As an example, the writer would like to offer some comment on the theory of rock bolt support described in Section 2. As mentioned in the paper, the prestress developed by rock bolts as commonly used is of the order of 10 lb./sq. in. and it would seem therefore that the concept of the "ring of compressed and strengthened rock" (Fig. 2) can be valid only in material which is naturally de-stressed, or has become so during the course of excavation. In tight country and high natural stress fields, stresses in the immediate vicinity of excavated surfaces can be of the order of several thousand pounds per square inch ; in these circumstances, it would seem that the relatively small compressive stress induced by rock bolting can have but little effect in itself, and the successful use of rockbolting for permanent support under conditions of this type must be attributed to other factors.

The design of the excavations for the Poatina underground power station, Tasmania, and their permanent support by the use of grouted, tensioned rock bolts and a thin reinforced "gunite" lining, have been described by Endersbee and Hofto (Ref. D1). This station is located about 500 ft. below the surface in tight, highly stressed mudstones. Rock failures under stress were observed in exploratory openings and the stress conditions around the main excavation for the machine hall were very carefully investigated, both by photo-elastic model studies and by *in-situ* stress measurements made in the rock during excavation. These studies indicated that the stress in the rock after excavation, at a distance above the flat roof of from 5 ft. to 10 ft. (i.e., about the middle third length of the bolts), could be expected to be of the order of 3,000 lb./sq. in. horizontal compression and 130 lb./sq. in. vertical tension. It was foreseen that the tensile stress would be relieved by some horizontal cracking, with the formation of separated flat slabs of rock still subject to the horizontal stress. The principal functions of the roof bolts in this situation appeared to be to prevent the buckling of the relatively thin horizontal slabs under the influence of compressive stress and, if necessary, to support their weight. The roof bolting was designed on this basis, with a reasonable margin of safety, and the roof as built appears quite stable. A total downward movement of the rock surface of about 0.17 in. has been recorded, of which about 0.10 in. represents the total observed width of the horizontal cracks and the balance is accounted for by elasto-plastic dilation.

As the authors would no doubt agree, rock bolts may be expected to act in rather different ways in differing conditions, and each application of this very versatile method of support requires some individual consideration.

Reference.

D1 ENDERSBEE, L. A and HOFTO, E. O.—Civil Engineering Design and Studies in Rock Mechanics for Poatina Underground Power Station, Tasmania. I.E. Aust Engg. Conference Papers, 1963. (To be published)

The Authors in Reply:

The discussion by Messrs. Colebatch, Endersbee and Paxton, being based on experience with rocks of a different type to those of the Snowy Mountains and under different operating conditions, provides valuable complementary information on the subject of grouted rock bolts. The following answers specific points made in their discussion.

(a) Anchors:

The authors' experience is also that slot and wedge bolts can be successfully used both in hard granite type rocks and in the softer sedimentary rocks such as slates and phyllites. Slot and wedge bolts were originally used widely in the Snowy Mountains Area. The change to expansion shell anchors was made for a number of reasons. External grout tubes as used with slot and wedge bolts were prone to damage in installation. The high ultimate pullout load capacity of 28 tons and upwards of some expansion shell anchors is considered a worthwhile advantage. Slightly over-depth holes are a convenience in forward bolting where the rock may be shot away from under the bearing plate in the next blast. Expansion-shell anchors can then be re-set further down the hole and retightened. This cannot be done with slot and wedge bolts. Rock bolts with expansion shell anchors can be fully pre-assembled on the jumbo and can generally be set and tensioned in a single operation, or two simple operations with the bearing plate and other accessories in place. The authors agree that both types can be satisfactory. The choice between them can well depend on personal experience under particular conditions, and on what crews are used to.

(b) Bolts:

The authors have found that the use of steel to B.S.970 : 1955, En5A has given additional strength without loss of elongation. As B.S.970 is a composition specification only, B.S.1968 : 1962 has now been adopted for steel but without regard to composition as welding is not involved.

(c) Washers and Nuts:

S.M.A. practice is the same as that quoted by the writers except that since the preparation of the Paper the hole in the bearing plate has been changed to a $1\frac{3}{8}$ in. × $1\frac{3}{16}$ in. oval to avoid jamming when the bolt shank makes an angle of other than 90° to the bearing plate.

(d) Grout Tubes:

Two alternative grout tubes holes are now provided—one on either side of the oval hole. The injection tube is now positioned some time after the bolt has been installed and tensioned and the duplicate holes give two chances of getting the grout tube in without striking rock. This method prevents damage to grout tubes by fly rock in forward bolting.

(e) Sealing of Holes before Grouting:

All insertion-type seals including rubber plugs have proved to be effective only about 50 per cent of the time in the broken-mouthed holes usually encountered in the Snowy Mountains Area and, at present, quick-setting cement plastered around the bearing plate after the bolt has been tensioned is the most used seal. This difference from H.E.C. experience may be due entirely to the types of drill-hole collar obtained in the respective rocks. The use of a spacer is not favoured, as it may reduce the effective length of a grouted bolt, whereas plastering enables the hole to be completely filled and the back of the bearing plate covered.

(f) Grouting of Rock Bolts:

Weak, spongy and powdery grout has also been found on the Snowy works. Excessive quantities of aluminium powder produce foaming in the grout, especially where the water-cement ratio is also high. The remedy adopted has been to find as precise a means as possible for measuring the quantity of aluminium powder and to exercise strict control over the water-cement ratio. Routine testing of 3 in. dia. cylinders 6 in. long shows that the grout being used in the Snowy Mountains gives over 2,000 lb./sq. in. at 7 days and 4,000 lb./sq. in. at 28 days. The grout used for all tests in Table V of the Paper contained aluminium powder in quantities just sufficient to prevent shrinkage.

Grouting tests on bolts in transparent cylinders has shown that without aluminium powder in sufficient quantity to cause a slight expansion, settlement shrinkage uncovers the anchor. The authors agree that the drilling out of rock bolts is an essential check, and this has been done using 6 in. dia. coring drills. However, the anchor itself may not always be recovered because of drill alignment difficulties.

(g) Bond to Bolts and Rock:

When bolts are subject to pull-out tests on work sites, or test sites, the jack bears on the rock outside the grout and therefore the test is believed to be a test of both bonds—bolt-to-grout and grout-to-rock. The grout to rock bond will, of course, also depend on roughness of the side walls of the drill hole. Tests, the results of which will be published later, confirm that there is no doubt of the adequacy of the bond between the grout and the rock.

(h) Protection from Corrosion:

Practice in the S.M.A. is to use pneumatically applied mortar or a wash of thick cement grout to protect all steel, as is the case in the H.E.C.

(i) Practical Consideration in Rock Bolt Placing:

In the Authority's practice "forward bolting" is the method normally used whenever it is necessary to support the rock before work continues. Ground, which at the time is standing satisfactorily without any support and might well continue to stand for some time, is bolted from the back of the jumbo.

With the drill jumbos used at present, the drifter units or three stoper units on the top deck, and the drifter units or stopers on the intermediate deck can install in 30 to 40 minutes all the bolts required for the two complete patterns (15 to 20 bolts) required for a five- to six-feet advance. The men working on the bottom (e jumbo are protected by its upper decks and can proceed si taneously with the drilling of the lifter holes.

Experience in the Snowy Mountains is that the men's morale when working under rock bolts is often better than under steel sets, provided that they are accustomed to rock bolts.

(j) Steel Sets and Rock Bolts Combined and Lagging Between Rock Bolts:

The use of light steel sets, themselves supported by rock bolts, as part arch segments, described in the discussion has not occurred in the Snowy Mountains. Rock bolts and steel sections, not necessarily taking the form of an arch segment, have, however, been used as support in the way described. Crown sets and wall plates were used before the introduction of rock bolts, but are now rare.

The smooth periphery obtained in the H.E.C. tunnels should be ideal for rock bolt and mesh support. Rough peripheries are the rule in hard rock such as that of the S.M.A. The use of wire mesh and auxiliary support between bolts was probably not sufficiently highlighted in the Paper. In the Murrumbidgee-Eucumbene Tunnel, which goes through considerable lengths of highly contorted schists, quartzites and phyllites, mesh and gunite were used extensively, as is also the case on current works.

(k) Failure of Rock Bolting:

In general, there has been no failure, in the sense of an promoted collapse, in any bolted tunnel or excavation on the Snowy Mountains Area. One collapse which occurred during a blast, before rock bolting had been studied in any detail and is described in Ref. 4, might strictly have been called an overbreak of major dimensions. In another case, before forward bolting was established as a standard procedure, a slab of rock broke off before bolts could be installed.

(l) Use of Mesh Pins:

Various types of pins have been used to hold mesh. One of these consisted of $\frac{1}{2}$ in. dia. rod bent into hairpin form and driven over a wedge. A 6-in. length of $\frac{1}{2}$-in. rod was then passed through the eye of the "hairpin". Another device was an 18- to 24-in. length of 1-in. × 1-in. × $\frac{1}{8}$-in. angle iron with slots cut in the exposed portion. At present the most used devices are intermediate anchors and surface anchors. The intermediate anchors are 18 to 24 in. long rock bolts, with expansion anchors. Surface anchors are short wooden plugs to which the mesh is fixed with staples.

(m) Costs:

The Commission's costs are of particular interest to the authors. Work in the Snowy Mountains is done under schedule of rates contracts and tendered prices are, of course, not necessarily the same as actual costs. The increases quoted of 45 per cent with steel sets in fully lined tunnels and 100 per cent in nominally unlined tunnels are the cost to the Principal as determined by the actual prices tendered.

In the Authority's contracts, prices for concrete in nominally unlined tunnels are given as:—

(a) price per cu. yd. for the first 80 cu. yd. in any section;
(b) price per cu. yd for concrete in excess of the first 80 cu. yd in any section.

In a 20 ft. 4 in. by 20 ft. 8 in. fully lined horseshoe-shaped tunnel, the pay concrete quantities for rock bolt supported and light steel supported sections are 2.83 and 3.93 cu. yd. per foot of tunnel respectively—which gives the figure of 40 per cent quoted in the Paper. An additional factor is that cement in concrete for backfilling overbreak is also paid for by the Authority.

In a nominally unlined tunnel the components of extra cost where steel sets are used are:—Extra excavation, the steel sets themselves, and the associated timber lagging, the 40 per cent increase in concrete and the cement in the overbreak. Totalled, these give the 100 per cent increase quoted in the Paper.

Concluding Remarks:

The authors fully agree that the ideal in tunnelling is a smooth bore with no shattering at the periphery. The Poatina tunnels are a happy application of the method to hydro-electric tunnels of substantial length, made possible by the nature of the rock, but at the present stage it is difficult to foresee the method being extended to granite and other hard rocks.

To Mr. J. F. Chappell:

Grouted rock bolts have been drilled out by taking a 6-in. diamond drill core. Conditions in the holes were as foreseen by Mr. Chappell, the bolt contacting the sides of the hole from point to point. However, in all bolts which had been grouted by the methods described in the paper and in Ref. 16, the grout was found to have filled the hole completely, notwithstanding the narrowness of some of the spaces. In grouting tests prior to the adoption of the present method, considerable trouble of the type referred to by Mr. Chappell was experienced. However, the drifters currently used for rock bolting give straighter holes than the jack-hammers which were used earlier.

However, the authors are firmly of the opinion that the key to success in this type of work, as in the prestressed cables mentioned by Mr. Chappell, is in the grout, and that the main factors in the grout are proper design and mixing of the grout, cement of the right quality, and adequate cleanliness. They refer Mr Chappell to Ref. 16 of the Paper.

To Mr. H. C. V. Woollard:

The authors agree with Mr. Woollard that rock bolts must be considered to act in different ways under different conditions. The part played by rock bolts in supporting excavations in ground which has initially had high inherent stresses is particularly interesting. They agree with Mr. Woollard that one way to look at it is to consider that the "support ring" referred to in the Paper represents the action only in ground of low inherent stress or ground which has been de-stressed (Fig. 5 of the Paper). The latter is, of course, the case in the zone surrounding an excavation made by blasting and in this case one might regard the "support ring" as a piece of countryside reconstituted by blasting and bolting.

In so far as the bolted zone has not been de-stressed, the stress situation is much less clear. One is tempted to suggest that the large unaccounted factor is the capacity of any rock, except the very poorest, to contribute to its own support. This capacity of the rock is primarily competence in compression and to a lesser extent in shear. The force provided by rock bolts on the other hand is competence in tension. There seems to be little doubt that the rock and the bolts acting together do in fact provide a complicated stress bearing system similar to geodesic vector structures.

Simmons Limited, Glebe, Sydney.

Attachment 4

Australian Academy of Sciences

Academy Symposium, November 1999

Rock mechanics and the Snowy Mountains Scheme

Professor E T Brown FREng FTSE
Senior Deputy Vice-Chancellor, University of Queensland

(Extract)

Rock Bolting

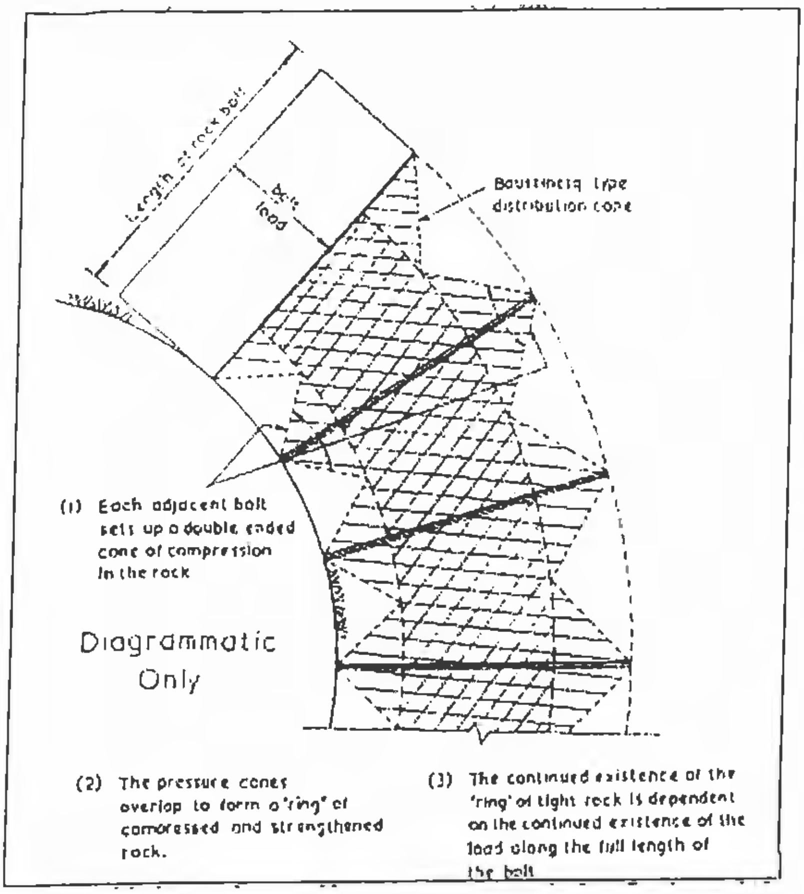
Although it had been used on a few projects in North America and France in the early 1950s, at the time of the design and construction of the early tunnels on the Snowy Scheme, rock bolting was not an established method of rock support in civil engineering either in Australia or elsewhere. On the Snowy Scheme, some rock bolts were used in the Guthega Project excavated in the period 1952-54, but the first major use of rock bolts in the Authority's works was in Tumut 1 power station excavated in 1956-57 (Pender et al 1963). This represented quite a major departure from the then traditional steel set and concrete support. Here again, the SMHEA was at the forefront of the application of this new technology in the design and construction of its underground excavations.

In the early to mid-1950s, it was generally held that the purpose of rock bolts was to pin surface rock (either individual blocks or bedded strata as encountered in underground coal mining) to more stable rock some distance from the surface of the excavation. At the time, mechanically anchored (slot and wedge or expansion shell) bolts were used. Rabcewicz (1957) carried out model tests which suggested that a rock mass consisting entirely of blocks or fragments could be held stable by systematic bolting. The team of investigation and design engineers working on the Snowy with the Assistant Commissioner, T A Lang, as the driving force proved, developed and applied this concept with remarkable effect. Indeed, it has been suggested that the development and use of rock bolting for permanent support of underground excavations was probably the most significant engineering development made on the Snowy Scheme.

At this point it is interesting to note that, at the time, and for some years later (eg Hoek & Brown 1980), rock bolts were referred to as providing "support". Today, it is usual to distinguish between support and reinforcement on the basis of the method by which the rock adjacent to an excavation is stabilised. Support is the application of a reactive force at the face of the excavation. Reinforcement is the improvement of the overall rock mass performance from within the rock mass by techniques such as rock bolts, cable bolts and ground anchors (Windsor & Thompson 1993). At the time of the construction of the Snowy Scheme, support was most often described as being "temporary" or "permanent". In their important paper on the use of grouted rock bolts on the Snowy, Pender et al (1963) refer, more helpfully and correctly, to "construction" and "permanent" support, although the term "temporary" was used in other Snowy publications.

In the mid-to late 1950s, a detailed series of laboratory experiments was carried out by the SMHEA to investigate the action and effect of rock bolts. Simultaneously, experience was gained with the practical application of rock bolting, initially on the Tumut 1 project. The laboratory experiments described by Lang (1961) and by Alexander and Hosking (1971) included model tests of the arched roof of the Tumut 1 machine hall using gravel and regularly shaped perspex blocks to simulate the rock mass; cubical box models of various sizes in which the boxes were filled with crushed rock, provided with model or prototype rock bolts and turned upside down with the open side facing downwards and often carrying an applied load; rod models; photo-elastic models using a solid plate of photo-elastic material or an assembly of blocks; and the famous inverted bucket model. In the latter case, "a household bucket was filled with gravel and the surface layer was bolted with model rock bolts with 1 inch (25.4mm) square bearing plates at both ends of the bolt. When the bucket was inverted, the lateral pressure developed on the sloping sides of the bucket was sufficient to support not only the gravel mass but also a central load of 50 lb (0.22 kN)" (Alexander & Hosking 1971).

Figure 5: Action of pattern rock bolting to form a self-supporting ring or arch

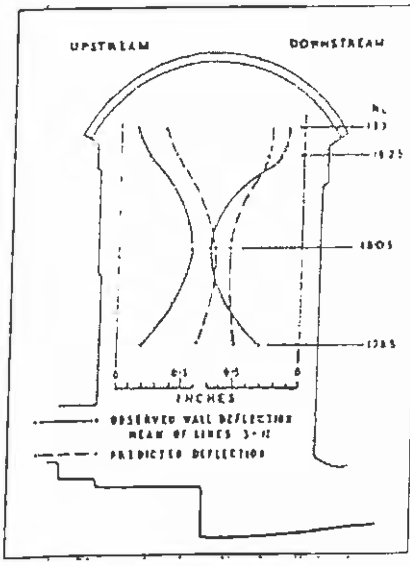


from Pender et al 1963)

On the basis of these experiments and through field experience, the Snowy team developed an understanding of the way in which systematic rock bolting in a jointed rock mass forms a self-supporting compression zone within the rock mass. This effect is illustrated in Figure 5. In addition, a set of design rules was developed for pattern rock bolting which related bolt length and spacing to block size (Lang 1961). These rules represented the state-of-the-art for many years subsequently (Hoek & Brown 1980). Lang (1961) also published pioneering analyses of the ways in which single rock bolts may prevent slip on single joints and single blocks of rock may be stabilised.

In the Tumut 1 machine hall, generally 4.6m long ungrouted mechanically anchored bolts on 1.4m centres were used in the walls. In the roof, 3.7m long bolts on 1.2m centres were used as "construction support" between the 1.2m square concrete ribs (Pinkerton et al 1963). The use of grouted rock bolts for permanent support was pioneered at Tumut 2 built a few years later. Generally, 4.3m long cement grouted bolts on 1.2m centres were used. Some 2.4m and 3.7m long grouted bolts were also used (Pinkerton & Gibson 1963). Following its successful use on these large underground excavations, pattern rock bolting, often with grouting, became an important feature of the several large tunnels constructed subsequently on the Snowy Scheme (Andrews et al 1964, Pender et al 1963).

MONITORING AND RETROSPECTIVE ANALYSIS



(from Alexander et al 1963)

Figure 6: Observed and predicted wall displacements, Tumut 2 Power Station

The final elements of the generalised rock mechanics program shown in Figure 3 are monitoring rock mass performance and retrospective analysis. Pinkerton et al (1961) indicate that the following monitoring measurements were made in the Tumut 1 underground power station excavation:

(a) measurement of strain in the reinforced concrete arch ribs;
(b) measurements of rock and concrete movements were made by means of precise survey methods, and by clinometers which had a very sensitive level;
(c) measurements of variations in the tension of selected rock bolts were made by means of calibrated rubber compression pads;
(d) rock noise measurements were taken."

The way in which some of the monitoring results were used to guide retrospective analyses during construction and to develop an understanding of the behaviour of the rock mass was outlined above. As was indicated earlier, the

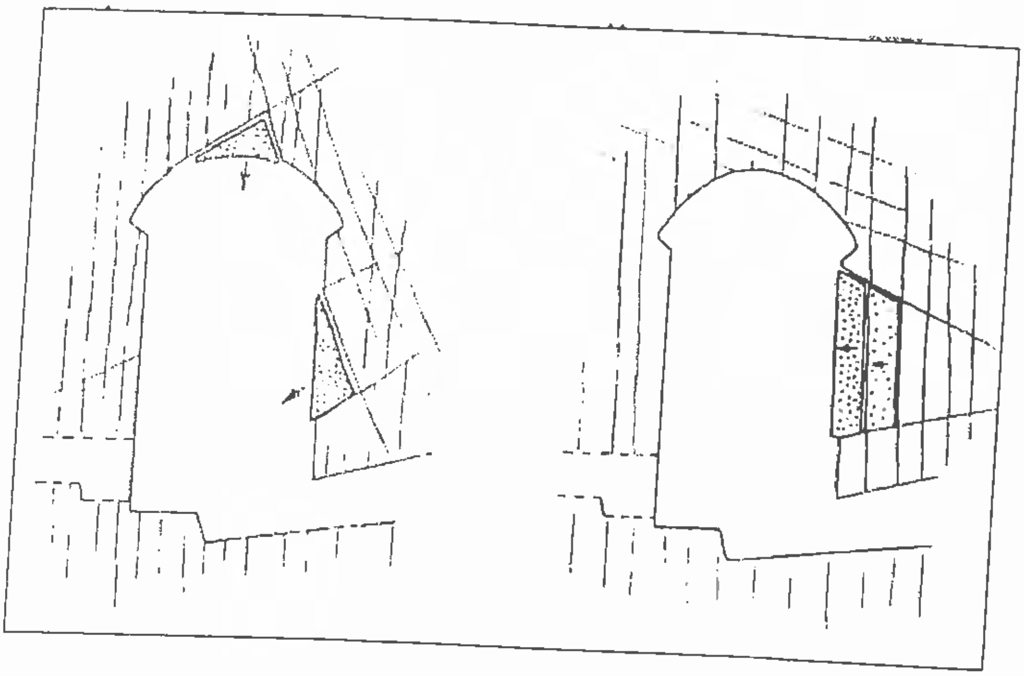
lessons learned in Tumut 1 influenced the investigation for, and design of, Tumut 2. The monitoring carried out at Tumut 2 and the results obtained are described in detail by Alexander et al (1963) and in less detail by Pinkerton and Gibson (1964). Measurements were made of temperature, strain and stress in the concrete of the roof ribs, closure of rib cracks and the joint between the rib and rock arch, rock strain in the arch, and displacement, dilation and angular deflection of the rock walls.

Figure 6 shows the means of the surface displacements measured on several survey lines on either wall of the machine hall excavation. Near mid-height on either wall 40ft (12.2m) below the abutments, the mean deflections were 0.5in (13mm) on the upstream wall and 0.7in (18mm) on the downstream wall. The predicted values shown in Figure 6 are consistent with a modulus of elasticity of the rock mass of 15GPa (Alexander et al 1963).

The monitoring techniques used reflected and advanced the then state-of-the-art. At the time, single and multiple point borehole extensometers as we now know them had not been fully developed although significant advances were being made in this area (eg Potts 1957). In Tumut 2, rod extensometers comprising 4ft (1.22m) to 14ft (4.27m) long rock bolts were used to measure the normal wall dilation. It was concluded that, in addition to elastic expansion of the rock arising from stress relief, there was opening of joints in the rock between depths of 8ft (2.44m) and 12ft (3.66m) (Alexander et al 1963). Possible types of block movement identified as being associated with joints are shown in Figure 7.

This approach to monitoring rock mass performance and interpreting the results obtained was advanced at the time and differs little from the approach likely to be used today although the required instruments are now available commercially and are more sophisticated than those developed by the Snowy engineers.

Figure 7: Possible failure mechanisms in jointed rock



(after Stapledon 1961).

THE SNOWY'S ROCK MECHANICS LEGACY

The work carried out on the Snowy Mountains Hydro-electric Scheme advanced the then state-of-the-art in rock mechanics and rock engineering for large tunnels and underground excavations. High level expertise was developed from the low levels pre-existing in Australia in almost all areas of underground excavation engineering in rock including site investigation and rock mass characterisation, design analysis using the photo-elastic method of stress analysis, the theory and practice of rock bolting and rock mass performance monitoring. This expertise led not only to the successful construction of the underground excavations of the Snowy Scheme but advanced the state-of-the-art internationally.

The high standard of rock mechanics work carried out on the Snowy Scheme was emulated in the hydroelectric developments undertaken in the latter part of the Snowy construction period by the Hydro-electric Commission of Tasmania (eg Endersbee & Hofto 1963, Maddox et al 1967). The

Australian mining industry soon took advantage of the rapid development of rock mechanics expertise that took place in the 1950s and 1960s. In the 1960s a number of Australian mining companies used the expertise built up on the Snowy scheme for advice on specific problems (May 1980). At the same time, Mount Isa Mines established what was, for some time, one of the strongest applied rock mechanics groups working on a particular mining operation anywhere in the world. These and other developments were aided greatly by the fundamental and applied rock mechanics research, and the training of students in the field, carried out by Professor J C Jaeger at the Australian National University from the late 1950s, by Professor D H Trollope at the then University College of Townsville from the mid-1960s, and soon after by the CSIRO which L G Alexander and G Worotnicki joined from the SMHEA.

The work carried out on the Snowy stands as a high point in the history of the development of rock mechanics and of underground rock engineering. It provided the impetus for the many Australian contributions made to geomechanics generally, to rock mechanics and to their application in the subsequent two decades (Brown 1991). The Snowy provided not only new knowledge and experience but the individuals who continued to develop the state-of-the-art, and to inspire others to do likewise, in a wide range of applications in the construction and mining industries.

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Rock Bolting Development Site, Lambie Gorge, Cooma
Snowy MountainsHydro-Electric Authority (SMHEA) PERSONNEL CREDITED WITH SUBSTANTIALLY CONTRIBUTING TO THE ENGINEERING OF THE ROCK BOLTING TECHNOLOGY

LEADERSHIP AUTHORISATION AND SUPPORT

Thomas Arthur Lang (born 1909), Staff No 16, started 21/11/1949 from being Commissioner Irrigation and Water Supply Commission, Queensland to becoming Associate Commissioner, SMHEA. He had the vision, the driving force and he inspired the young and capable personnel to apply themselves to engineer the existing roof bolting method, mainly in coal mines with sedimentary rocks, and existing hard rock bolting practice also beginning to be utilised on some tunnelling projects overseas. It was because he facilitated the specialised training of a number of promising young staff members with the United States Bureau of Reclamation, USA, who were themselves well established in the project work required by SMHEA, that he had encouragement from his trainee Lance Endersbee to explore the usage of rock bolting. Lang's paper to the American Society of Civil Engineers in New York in October 1957 established the unique advance made by his staff since July 1956 to give a sound mathematical basis for the use of rock bolts in hard rock tunnelling.

Edward Burnett Pender (born 1911), Staff No 1023, started 6/2/1950, gave enthusiastic support the the rock bolting work as Senior Executive Engineer Civil Design and Scientific Services. Some considered him a little eccentric but he left a dominating impression and continued the lead support in 1959 after T A Lang had left. He was joint presenter with others on the subject for several papers to international engineering societies.

Thomas David James Leech (born 1902), Staff No 1178, started 12/12/1950 from being Professor, Dean of Engineering, Auckland University, NZ to be Engineer-in-Charge Scientific Services Division, SMHEA, and so the setting up of five applied science discipline engineering laboratories. He encouraged enquiry and innovation.

David Anderson (born 1921), Staff No 1180, started 19/12/1950 from United Kingdom to be Supervising Engineer and Deputy Head of Scientific Services. He encouraged the science research of rock mechanics and thus for the SMHEA to become the leader in the world and the education and training of personnel, much sought after by others.

Ivor Lennox Pinkerton (born 1915), Staff No 8, started 24/10/1949 and was closely involved with the civil design of most structures for the SMHEA water storage, water diversion, and hydro-electric works. He became Engineer-in-Charge Civil Design in his mid-thirties. He presented several papers on the design of the large underground caverns and their successful construction to international engineering audiences.

Kenneth Edwin Andrews (born 1911), Staff No 1033 and supervised Major Contracts Division where the rock bolting practice required strong support for the SMHEA supervising engineers, geologists and inspectors watching the contracted works to ensure what was ultimately hidden had been thoroughly done according to design. He was joint author with others of several technical papers.

Howard Ernest Dann (born 27/4/1914), Staff No 1128 and supervised Investigations Division, and later rose to the position of Commissioner, SMHEA. He was joint author with others of several technical papers to do with unlined tunnel construction methods.

Walter Peter Hartwig (born 1912), Staff No 2020, started 29/1/1951 and was senior resident engineer to supervise the construction contract for the Tooma Dam and Tooma-Tumut tunnel Works 1958-60. The adoption of successful rock bolting techniques were achieved as a new construction method using the latest developments in rock bolt particulars. Some particulars were to be added to the earlier specified requirements for the Tumut 2 Project.

Alexander Ross McIntyre (born 1923), Staff No 1001, started 3/1/1950 and was resident engineer to supervise the construction contract for the Murrumbidgee-Eucembebne tunnel Works 1958-60. The adoption of successful rock bolting techniques were achieved as a new construction method using the latest developments in rock bolt particulars. Some particulars were to be added to the earlier specified requirements for the Tumut 2 Project.

Robert John Paton (born 1924), Staff No 6257, started 31/10/1955 and was resident engineer to supervise the construction contract for the Tumut 2 Power Station and tunnel Works 1958-61. The adoption of successful rock bolting techniques were achieved as a new construction method using the latest developments in rock bolt particulars. Some particulars for rock bolting were gained from the experience of tunnel contracts Tooma-Tumut and Murrumbidgee-Eucumbene.

Karl Erhardt Timmel (born 1910), Staff No 3080, started 27/6/1951, gave engineering leadership to the Physical Sciences Branch of Scientific Services Division.

LEADERS IN THE APPLICATION OF ENGINEERING AND SCIENCE

Daniel George Moye..(born 1920), Staff No ?, started ?/12/1949 from being resident geologist at Warragamba Dam for 31 months after University of Sydney, BSc (Geology). He was head of Engineering Geology Branch of Scientific Services Division and it was to him that the instruction from Lang to investigate for rock bolting usage was written in July 1956. Soon after his Branch proposed and were authorised for two series of experiments. The result of these experiments lead to pioneering the theoretical part and firmly established design criteria for understanding the action of rock bolting in a wide variety of hard rock conditions. He took leave of absence to become visiting Professor of Engineering at University of California, Berkley, USA, lecturing in geological engineering, September 1962 to July 1963, so spreading the lessons learnt in the new engineering discipline of geomechanics.

David Lafeber (born 1911), Staff No 4105, started 13/3/1953, a graduate of University of Amsterdam, with doctorate specialising in petrographic examination, and worked in Engineering Geology Branch Scientific Services for five years. He presented his findings from the first detailed experiments that set new concepts in understanding the use of reinforcement of fractured rock using rock bolts. In February 1957 he created a powerful illustration of the principles he had enumerated. With a set pattern of several model-size

brass rock bolts (about 3mm dia) in a 3-gallon conical bucket full of crushed rock turned upside down, he suspended an equal weight to the crushed rock (about 18kg) from one of its central rock bolts. The bucket remained on display in this condition and was used to generate interest in the use of rock bolting to a wide audience for many years.

Clive Charles Wood (born 1927), Staff No 2022, started 31/1/1951, BSc (Geology), BE (Civil), University of Sydney, was involved from the first strength tests conducted in the Lambie Gorge test site, also examining the deformation for the bolt anchorage recovered after blasting. Investigations and tests were also carried out in the tunnels on rock bolting strength working in Engineering Geology Branch Scientific Services for ten years, becoming Executive Engineer, during which time he took leave to obtain a doctorate in soil mechanics from Imperial College, London.

Aubrey Darnell Hosking (born 1919), Staff No 2039, started 26/2/1951, BE (Civil) University of Western Australia, was head of Engineering Materials Branch of Scientific Services and established a soil testing laboratory. He was given experience with United States Bureau of Reclamation, Denver, USA, then took a year's leave for a diploma from Imperial College London. He was strongly encouraged by T A Lang, and was instrumental in conducting a very wide variety of rock bolting experiments in his soils laboratory and was particularly gifted to negotiate with contractors in the application of the latest advances from these experiments. Of particular note is Aubrey's development of more sensitive strain gauges that lead to certainty of performance measurements in all major civil engineering structures, including underground works. He is joint author with E B Pender and R H Mattner of a technical paper on grouted rock bolting for permanent support.

Jurij (George) Worotnicki (born 1919), Staff No 3205, started 1/9/1952, with a BE (Mechanical) from Polytechnique Institute, Ukraine, where the emphasis was in mathematical science in geodesy, in which he lectured. He worked in Engineering Physics of Scientific Services, specialising in the mathematical analysis of rock stresses around tunnel type excavations verified by photoelastic models. He was strongly encouraged by T A Lang in devising an analysis and in determining the sizing and spacing of rock bolts based on rock properties.

Laurie George Alexander (born 1917), Staff No 4083, started 2/3/53 and as supervising scientific officer was a world's first pioneer in the development of in situ field measurement techniques of hard rock stresses, which enabled a matching design of the rock bolting required to counteract the internal force requirements of the rock surrounding the excavation.

Kenneth George Aubrey (born 1926), Staff No 1055, started 3/4/1950 and was partner in the theoretical rock bolting research in partnership with L G Alexander and J Worotnicki. Together they presented a technical paper on rock mechanics.

John Lang Rea (born 1924), Staff No 1020, started 1/2/1950 and was resident engineer to supervise the construction contract for the Tumut 1 Power Station and tunnel Works 1954-8. The introduction of rock bolting at the pre-contract stage lay the ground for a vital new construction method at the insistence of SMHEA, who carried the risk.

John Ingoldby Hilton (born 1931), Staff No 7229, started 8/8/1956 and as young engineer experimented with modelling the behaviour of jointed rock with the presence of rock bolts while working in Physical Sciences Branch, Scientific Services.

CIVIL ENGINEERING STRUCTURAL DESIGNERS

Lance Aubrey Endersbee (born 1925), Staff No 1034, started 22/2/1950 and was one of twelve early in 1952 selected to be given 12 months experience with United States Bureau of Reclamation (USBR), Denver, USA. It was the design for the first SMHEA trans-mountain tunnel, Eucumbene-Tumut that he was assigned within the group also responsible for underground structures. His supervisor accepted his enthusiastic proposal to show optional rock bolts as a temporary roof support in the design drawings; it was an innovation for USBR at the time, he having read an internal report on their use as a temporary support in a small tunnel. Later in the Cooma design office, Lance was a partner in using the SMHEA theoretical rock bolting research required for designing permanent rock bolt reinforcement for major tunnelling contracts. He rose to the position of executive engineer Civil Design.

Allen Dunlop McConnell (born 1923), Staff No 26, started 12/12/1949 and was a partner in the theoretical rock bolting application required for major tunnelling contracts. He rose to the position of executive engineer Civil Design.

John Richard Hunter (born 1921), Staff No 27, started 12/12/1949 and was a partner in the theoretical rock bolting application required for major tunnelling contracts. He rose to the position of executive engineer Civil Design Tunnels and Aqueducts.

Stoyan Rogleff (born 1927), Staff No ?, started 8/9/1952 and with Dams and Tunnels Branch was engaged in the planning of rock bolting requirements for major tunnelling contracts, then with the construction coordination with site resident engineers and the regular inspections of the Works.

CONSTRUCTION SITE ENGINEERS AND GEOLOGISTS

Kenneth Raeburn Sharp (born 1927), Staff No 1026, started 10/2/1950 and was pioneer on-site geologist for the first of the engineering works in Upper Tumut Region of the SMHEA Works. The engineering for the tunnels and caverns for the first underground power station fully specified by SMHEA, Tumut 1, did successfully apply rock bolting in its earliest form for the first time in such large structures taking account of the geological information obtained. Exploratory core drilling followed by exploratory tunnel reading of the geology fed information into the paper presented by TA Lang in New York, USA in October 1957 that established the rock bolting practice precedence. At that time only those rock bolts angled to dip below the horizontal were capable of being effectively grouted. The application benefits of rock bolting were quickly recognised by the consortium contractor's head-office in France.

David Svenson (born 1924), Staff No 3242, started 10/10/1952 as geologist and relieved Ken Sharp at Tumut 1 Power Station project to wards the end of the construction period.

David Hiley Stapledon (born 1930), Staff No 2194, started 13/11/1951 and was pioneer on-site geologist for the second more extensive underground power station fully specified by SMHEA, Tumut 2, part of the total hydro-electric development in Upper Tumut Region of the SMHEA Works. The same expertise in geological information allowed a greater use of fully grouted rock bolting to be applied throughout the excavations without any failures, better speeds, economies and improved safety.

Peter Albert Ellwood (born 1925), Staff No 6088, started 22/4/1955 as an engineer supervising Eucumbene Dam contract to later supervise the installation of rock bolts in Tumut 2 Project work.

David Howe Probert (born 1934), Staff No 9148, started 21/4/1958 and was geologist for Tooma-Tumut tunnel Works. The adoption of successful rock bolting techniques were achieved as a new construction method using the latest developments in rock bolt particulars. Some particulars were to be added to the earlier specified requirements for the Tumut 2 Project.

Richard Hocking Mattner (born 1929), Staff No 9270, started 17/9/1958 and came with a background as a mining engineer. He was resident engineer to supervise the construction contract for the Murrumbidgee-Eucumbene tunnel works. The adoption of successful rock bolting techniques were achieved as a new construction method using the latest developments in rock bolt particulars for the more difficult, more jointed, geological conditions encountered. He is joint author with E B Pender and A D Hosking of a technical paper on grouted rock bolting for permanent support.

ROCK BOLT AND SYSTEM TESTERS

George David Chatfield King (born 1928), Staff No 7155, started 9/5/1956 and responsible for providing the practical technical data for the installation of five categories of rock bolts available for use in July 1957. He rose to the position of executive engineer Major Contracts.

David Crouch Herbert (born 1920), Staff No 4014, started 8/1/1953 as engineer and carried out extensive tests on rock bolts of various styles in the Engineering Construction Materials laboratory of Scientific Services Division.

Rudolph Ernst Belin (born 1920), Staff No 7278, started 22/9/1956 as scientific officer from New Zealand and carried out tests on rock bolts in Engineering Physics laboratory of Scientific Services Division and followed their installation in the underground works of the Upper Tumut projects.

Donald Charlton Kennard (born 1926), Staff No 1050, started 27/3/1950 as engineer to analyse the desirable mix to get optimum performance for the grout to be used with the rock bolts.

William Francis Navin (born 1919), Staff No 7351, started 26/11/1956 as engineer to design the method and equipment of batching the grout for pressure injection to seal the rock bolt in its surroundings, under the severe tunnelling environment close to the recently

excavated face. He played a vital role in instructing the inspectors supersising the contracted rock bolting work

Ian Donald Main (born 1925). Staff No 4142, started 20/4/1953 as Chemist in Physical Sciences Laboratory of Scientific Services Division and carried out coating tests on rock bolt external components.

John Nairne R Anderson (born 1935), Staff No 8127, started 11/12/1956 as engineer and carried out rock bolt pull out tests for the Tooma-Tumut tunnel contract.

Robert Turner Brodie (born 1937). Staff No 10337, started 23/11/1959 as engineer and carried out rock bolt pull out tests in Lambie Gorge.

ENGINEERING HERITAGE OF NATIONAL SIGNIFICANCE
ROCK BOLTING & SPECIALITY OF ROCK MECHANICS
Rock Bolting Development Site,
Lambie Gorge, Cooma, NSW

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APPENDIX F – "ENGINEERING HISTORY IN COOMA ROCK" LECTURE

- Public Lecture "Engineering History in Cooma Rock", researched, prepared and presented by Walter B Mills to Engineers Australia's advertised meetings, 2007-8, (a) text, (b) condensed copy of slides accompanying the text, and (c) handout to attendees.
- EA Lecture flyer for Sydney, 4 June 2007
- EA Lecture flyer for Cooma, 23 August 2007
- EA Lecture flyer for Canberra, 24 October 2007
- EA Lecture flyer for Hobart, 30 October 2007
- EA Lecture press release for Townsville, 26 August 2008
- Lecture advertising story in *Sydney Morning Herald* newspaper, "Nifty idea made a whole lot of difference", June 4, 2007
- Lecture advertising story in *Cooma-Monaro Express* newspaper, "Local history is rock solid", August 21, 2007, and "World first revisited", August 23, 2007

SLIDE 1 - TITLE

It is only 50 years since the new concept in rock bolting was introduced to the world of tunnelling in hard rock.

Rock Bolting had been in use for 50 years earlier[1], beginning in the coal mines, but it was of a different concept. The real development work for Rock Bolting was done in conjunction with the building of the Snowy Mountains Scheme requiring massive underground caverns and long tunnels, deep underground.

It was Professor Ted Brown of University of Queensland, who said, that the Snowy Mountains Hydro-electric Authority's development and use of Rock Bolting "was probably one of the most significant engineering developments on the Snowy Scheme"[2].

Throughout this talk I will use the abbreviation SMA for SMHEA.

The Scheme's headquarters was established in Cooma, NSW, that lead to the Snowy Mountains. It was here that the visionary engineering project, that captured the run-off from the mountains, was designed and managed.

SLIDE 2- INTRODUCTION

My interest in this heritage site began in July 2003.

Rock mechanics is not my field of engineering expertise.

My engineering background with the SMA began in 1959.

The engineering heritage of how tunnels can be can be made safe by simple and economical means can be easily appreciated, and it is an engaging story of how the rock bolting system evolved.

The Rock Bolt itself was simply a rod of ductile steel up to about 25mm diameter that could be made to anchor itself at the bottom of a deep hole in hard rock, and be capable of being tightened up with an external nut until it was fully stretched, but not to breaking point. ®Thus the bolt was used to full strength capacity, and when used with others in a pattern according to the rock structure encountered, could lock the movement of the exposed rock to almost eliminate any tendency for tunnel collapse. But it had to be done within a few hours of the tunnel's creation for best effect. (®, throughout lecture, means show sample)

SLIDE 3 - BACKGROUND PICTURE

Here is the picture of the principal Rock Bolt pull-out testing experimental site in Cooma.

See the natural rock outcrop; it is at the downstream end of a short gorge, with deep rock pools

See the shattered rock blasted away from the rock face;

this has come from the need to create a fresh rock face once all the testing positions were used up.

SLIDE 4 - SITE CLOSE-UP

1. See the rock face peppered with holes of the testing positions;
2. see the steel bolts poking out of the holes. Here they checked what gave way first - the bottom-of-hole anchor, the nut thread, or the bolt shaft itself; they measured the pull-out force required for each type of system offered by each tunnelling contractor before it was approved for use. It was important to develop the full strength of all the materials used.
3. see the vertical split hole-line of the fractured rock face, so that a new working face could be made after putting explosives down these holes and blasting off the surface layer that had been fully used up.

It is on the banks of a creek in the heart of Cooma, easily reached with a 10minute walk. There are enough remnants of the tests carried out here to get a window into the huge leap forward gained by the dedicated work of many of the engineering and scientific team. Step by step they removed guess-work from the use of Rock Bolts.

SLIDE 5 - AERIAL PHOTO

Here is the aerial view of the location, overlaid with the property boundaries.
The "important" arrow points to the rock bolt testing site in Lambie Gorge.
Note the red roofs of the testing laboratories, the one directly north being for Engineering Materials.
The road frontage to the north of the laboratories is the Snowy Mountains Highway, heading west and south into the Snowy Mountains.

SLIDE 6 - GORGE

Here is a view from the edge of the last rock pool of Lambie Gorge, looking downstream. In the distance you can see the red roof of the nearest Laboratory, first established in 1952-3.
The rock containing the principal test remnants is on the-top-right. Thus you can see the curtilage relationship of the laboratory to the principal outdoor test site.
The local branch of Engineers Australia, Monaro Group, in October 2006 submitted their application for listing of this Rock Bolt testing site on the State Heritage register. In due course it is hoped that a nomination can be completed for recognition as a engineering landmark.

SLIDE 7 - OUTLINE (with need for click points)

I want to take you on a engaging journey through the story of the Rock Bolting and the development of rock mechanics that occurred during the span of six years, 1956 to 1962. It was totally stimulated by the demands of the work. Follow the outline of what I plan to tell you in this talk.

- First, I explain the historical engineering scene for tunnelling and in the use of Rock Bolts.
- Then I will tell of the principal research and development phases and people that allowed the SMA tunnelling work in hard rock to revolutionise the existing practices.
- Old habits die hard, as the saying goes; the implementation of the changes for the underground work presented their own challenges and intriguing stories.
- Then I give you a picture of the final form of the SMA's Rock Bolt.
- There is a literal "gold mine" of engineering history on my subject and I am just retelling the story; I share with you the rich sources I have used.

SLIDE 8 - HISTORICAL SETTING TITLE

First the Historical engineering scene for the SMA tunnelling work.
In 1956 the 26km of tunnels connecting the eastern flowing Eucumbene River to the western flowing Tumut River was under construction. It led through the cavern for the first underground power station. The French contractor in the cavern was required to use Rock Bolts to temporarily pin disturbed rock onto sound rock, and supplemented them with props while concrete arches were installed. Not all miners and their managers were convinced of the reliability of Rock Bolting by itself, at this point of time, since it was relatively new a practice in utility projects.
At the same time in Cooma, a number of SMA science laboratories were functioning, ready for their expertise to be mobilised for needs arising in design and construction.

SLIDE 9 - CLICK POINTS OF HISTORICAL SETTING

It was in April 1956 that, before the concrete roof arches were installed, a huge block of rock (of about 40 ton) fell from the cavern roof and it contained a number of Rock Bolts in it[3].

- **No one was injured but it initiated an immediate thorough analysis from senior management.**
- **The use of Rock Bolts date back to 1912 and were used thereafter progressively more commonly, and worldwide, in roof support in soft materials such as in mines. The use in hard rock began in 1939 in Sweden[1], and it was recognised then that there was the potential to do more than just hang the surface exposed rock from more sound rock behind it.**
- **What were the criteria to be applied for design purposes remained for another opportunity, and that came into the mind of the SMA leadership.**

SLIDE 10 - TOM LANG #16

Tom Lang, CBE, was the civil engineering sub-leader to the overall head, Bill Hudson. He was appointed at age 39 from being Commissioner of water and irrigation in Queensland. He was an imposing personality and shared Bill Hudson's drive for excellence and thoroughness. It was Tom Lang who drove the organisation to get to the bottom of the rock mechanics problem to understand all the factors required to design the rock support using Rock Bolts[4].

As the consequence of very concentrated research, he was able to deliver a ground-breaking paper on the subject to the American Society of Civil Engineers in New York in October 1957[5].

It was Tom who had originally put together an agreement between USA administration and the Commonwealth of Australia for the US Bureau of Reclamation to train the SMA's aspiring young engineers in preparing designs and specifications for tunnel and dam projects.

Notice his staff number. Those who joined in 1949, from its start 17 October, had these numbers, less than 100. As we go through you will get a picture of a person's starting date by their staff number. From 1950 onwards a 1000 was added to the number for each successive year.

SLIDE 11 - TED PENDER #1022

When Tom Lang left in 1958 it was Ted Pender who took up the supportive leadership role needed to carry on the two years of work done to that date. His colleagues thought him to be eccentric, but he was one with them and committed to feed helpful data into the team effort[6]. He was the one who maintained the support from his executive position in continuing the research activity for Rock Bolts. It was Ted Pender who received the IEAust medal for the outstanding annual conference paper in 1963, together with two other colleagues. It was a paper on Rock Bolting[7]. Notice Ted's badge; the SMA issue for years of service; bronze, silver or gold.

Ted would have been entitled to wear a gold one since he retired after 21 years of service. He had staff Number, 1023, ie he joined in 1950, serial number 23 of staff engaged in the first year. I joined in 1959, the 10th year since the start, so my number started with 10.

SLIDE 12 - PROF. TOM LEECH #1178

Professor Tom Leech came first from University of Sydney via being Dean of Engineering, University of Auckland, NZ 1940-50, from where he was recruited to SMA. He had a distinguished scientific leadership investigative role in WWII and for NZ, and continued this commitment to applied research and training. He set up all the scientific laboratories. He saw the need to train specialised inspectors of the contractor's work. These people were to be the independent checkers on the job who would ensure that there were no compromises in quality.

The fact that there were physicists, chemists, geologists, and material testers meant that there was an ideal set-up available to respond to the challenge of understanding Rock Bolt design and the developing science of rock mechanics.
The personal style of his leadership meant that he was always engaging with every aspect of the laboratory work. It was not uncommon for the heads of laboratories to use their lunch travel to home to discuss issues of the day by accepting his offer to be taken collectively in the car pool mini bus or in his Humber Super Snipe car; these discussions would often extend into the afternoon after the return journey. Prof Leech had an engineering supervisor as his deputy. At the time when the Rock Bolting research was started it was Eric Warrell who was deputy.

SLIDE 13 - DAVID ANDERSON # 1180

But in 1957 the deputy was promoted and Ted Pender stepped in for a short time followed soon after by David Anderson. Much was still to be done at this stage and David saw to the task of having the laboratories able to be registered for quality assurance work under a national code called NATA before Tom Lang was to deliver his Rock Bolting paper in New York[8]. All this was at a hectic pace, in parallel with the other demands on the laboratories associated with the Snowy Mountains Scheme data collection in surveying, hydrology, road making, aqueduct and dam construction.

SLIDE 14 - RESEARCH AND DEVELOPMENT TITLE

Topic 2 is the research and development phase.

SLIDE 15 - DOT POINTS OF R&D

It is here that I give you a picture of the mix of people within a wide range of scientific and engineering disciplines.

- There were about nine people who played a part in developing the Rock Bolt solution and advanced rock mechanics to be an established applied engineering science in its own right.
- There were various stages in finding the optimum components for the Rock Bolt and in extracting all the engineering structural properties of the rock met in tunnelling. The way the rock behaved after tunnelling had to be understood in order to be sure that the design would last.
- The very final stage was to move from using Rock Bolts just as a construction or temporary system to making them capable of being a permanent component of the exposed rock faces; able to remain submerged in water tunnels, or able to remain secure, safe and long lasting for all structures underground.

SLIDE 16 - DAN MOYE # 46

The key person of great ability and talent, without any doubt was Danny Moye, honours graduate in Geology from Sydney University in 1941 who had been taking the science specialty and applying it to give expert advice for engineering design and construction purposes.
He conceived new ways to define the graduation of rock of the Snowy Mountains in its degrees of weathering[9] because of his thorough observational and investigative approach from the very beginning of his employment. He began in Upper Tumut in Feb 1950.
Not only were the stages of weathering of the various rock types obtained, but the approximate depths of weathering were established over large areas[4] by seismic refraction surveys.
He became a partner in the engineering design phase. His personnel skills were matched to his leadership skills as he responded to Tom Lang's team assignment[10] to find solution to the multi-faceted task to interpret the rock and bolt interface deep underground.

From his position as head of Engineering Geology Laboratory he developed an immediate strategy for an expert team of five disciplines to contribute to a Rock Bolt report[11] of their possibilities and limitations. (This was followed up by a more detailed report in July 1957 with the five authors being D G Moye, L A Endersbee, Dr D Lafeber, G D C King, J L Rae.)[11] Dan's no-nonsense approach from his strong management position meant that, throughout the tunnelling period when final assessments were being made, the on-site geologist never had do battle with comprising or unappreciative engineers, managers or contractors.

SLIDE 17 - CLIVE WOOD # 2022

Clive Wood came with qualifications in both geology and engineering. Ranging between the construction site and the laboratory , he began experimenting and examining the anchoring of the Rock Bolts through the deformation pattern ® and by pull-out tests. Here he is in the severe climate of the mountains. Clive played a crucial team role in developing on-site installation practices and assisted the contractor's supervisory staff in applying the required means of making the Rock Bolts a permanent item by cement mortar encapsulation within their hole. Thus, he, of all those involved, had direct personal association from the start to the finish of the Rock Bolt development that took place with SMA.[12]

SLIDE 18 - KEN SHARP # 1026

Ken Sharp went straight from an honours degree in Geology at Sydney University to live in the Upper Tumut region. Here was an enormous task of exploring by geological mapping on the surface, then by diamond drill boring small diameter holes, but to retain a central core from the hole. to record the geological meaning. Here he is seen doing that. ® Holes ranged down to 600metres (2000ft) deep to intersect the underground construction locations. They were also drilled at the end of exploratory tunnels. There was excellent collaboration between surveyors, geologists and engineers[4]. Ken was the head geologist for the first underground cavern for T.1 Power Station, and became skilled in the new profession of engineering geology.

SLIDE 19- REPORT ON GEOLOGY

As a result, a Report of five volumes was produced under the watchful eye of Dan Moye - each volume was 2cm thick. This Report gave a new approach by interpreting the data, so that it assisted the engineering design and in informing tenderers for the construction. Copies of this report were used for instruction in final year lectures at Sydney University and at other similar institutions[13].

SLIDE 20 - GEORGE WOROTNICKI # 3205

George (Jurij) Worotnicki with a BE (Mechanical) from Polytechnique Institute, Ukraine, where the emphasis was in mathematical science in geodesy in which he had lectured, became a very important member of the SMA team in the Engineering Physical Sciences Laboratory. He there specialised in the mathematical analysis of rock stresses around tunnel type excavations and verified his findings by photoelastic models. He was strongly encouraged by T A Lang in devising an analysis and in determining the sizing and spacing of rock bolts based on rock properties. When the rock fall happened it was Tom Lang who sweated on him for an explanation; George worked 34h straight to complete his analysis[14]. George worked under the head of Physical Sciences Laboratory, T Kevin Hogan (# 1590), former chair of ACT Div. of IEAust (1946), an eminent engineer, mathematician, researcher and educationist.

SLIDE 21 - PHOTOELASTIC PICTURE
These photoelastic models were the best solution at the time to a very complex analysis problem before the days of electronic computing. It was a specialty for George. Clear plastic material when squeezed and viewed under polarised light makes these patterns. Today they entertain children at "Questacon" Science and Technology Centre in Canberra with such a thing. George demonstrated that, for a certain Rock Bolt spacing compared to their length, it was possible to produce a band with uniform compression away from each end effect of the bolts. In the two diagrams, the one on the right was preferred. This meant that the bolt had to be at least twice its spacing from the next bolt; the one on the left had a ratio of only one-and-a-half times[15]. This minimum ratio of two turned out to be right in most real rock situations encountered.

SLIDE 22 - ROCK BOLTING THEORY PICTURE 1
Thus in a tunnel (magenta colour) you can expect the broad yellow band of uniform compression when long bolts are required (for other reasons) in a arch pattern of bolting[15], but ....

SLIDE 23 - ROCK BOLTING THEORY PICTURE 2
when short bolts are sufficient, a narrower band is produced in the arch, but it requires more bolts[15].

SLIDE 24 - LANCE ENDERSBEE # 1034
Lance Endersbee was in the first batch of twelve young engineers sent to be trained with the US Bureau of Reclamation - for him it was the design of tunnels and underground structures[4] in their Denver office. He tells the most intriguing story of how, while as a junior there, working on the actual SMA tunnel design drawings, he had read a recent USBR article on the use of Rock Bolts in a small tunnel. From this he decided to show them in his drafting for the large SMA tunnel and was delighted that his experienced supervisor , although he had not used them himself in similar major works in USA like Hoover Dam and Central Valley Project in California, was convinced that the new idea was acceptable. In retrospect, he could see that he had undergone an unique training experience creating a confident and mature sense to the engineering team effort being undertaken in Australia[4].
Lance on return to the SMA design office in Cooma took a leading part in following the design research requirement for Rock Bolts on all jobs. Rock conditions encountered were such that it was possible to allow much of the tunnel length to be unlined, just relying on Rock Bolt reinforcing for the exposed rock stability.[4]
He soon after took this knowledge to the Hydro-Electric Commission of Tasmania, but on leaving SMA he was presented with a chrome-plated Rock Bolt as a memento[16]. In 1999 in a technical paper referring to rock bolting he said, "the Snowy had led a major change in world tunnelling practice in hard rock"[4].

SLIDE 25 - AUB HOSKING #2039
Aubrey Hosking is regarded by most to be the man who shouldered the majority of the advances in Rock Bolt design after the first phase of developing basic principles for them[8]. Nevertheless he was a team man, and he was highly motivated as well as being persuasive of others for their cooperation. He led the expanded laboratory testing after the first six months of analysis, and was instrumental in establishing good understanding with the many contractor's resident engineers to ensure that best practice was understood and adhered to at the management level. This further applied to the crucial team leadership role in developing on-site installation practices in making the rock bolts a permanent item by cement mortar encapsulation within their hole. There were so many separate tunnelling contracts going on in the early 1960s.

SLIDE 26 - MATERIALS LAB TEST RIG

Here is Aub on top of a 1.2metre cube test rig with an open bottom where he had within it, a pattern of Rock Bolts in crushed rock of uniform size. This set-up was like an extreme case of highly fractured rock after an explosive blast in mining the tunnel. It was shown that a pattern of rock bolts in the crushed rock could hold the whole together, between the parallel sides of the box, when the spacing of bolts was less than seven times the average diameter of the crushed rock. This was another important criterion because rock normally has fracture lines within it. Notice the hydraulic hacks built into the sides of the box. He was able to measure all manner of behaviour under varying side-load conditions as well as weights suspended from the Rock Bolts[5]. Aub was eminently supported in all the laboratory testing of all materials by David C Herbert.

SLIDE 27 - HERITAGE SITE CLOSE-UP

Going back to the heritage site, note the look of the bolts in this close-up. See firstly on the left the bumps on the threaded bolt, these were an added feature to improve the bond when the ductile medium tensile steel bolt is enveloped in concrete. They had already learnt how dangerous it was to use high tensile steel that gave insufficient warning of breaking before being over stretched. Note the hollow bolt to the right; by using a hollow bolt it could become the de-aeration route through the bolt from the far end of the hole. The creation of this hole was an amazing craft from the Titan steel making rolling mills in Newcastle and Wollongong - a malleable iron centre was rolled within the mild steel billet as it was rolled down in size[17]. When to size from the continuous rolling of the rod, it was cut into transport lengths, then the malleable iron centre was pulled out like chewing-gum while it was all still red hot leaving the lengths with a hollow centre. Aub, with his high profile on steel quality and test requirements, had the ability to negotiate with Titan to manufacture this special rolled product to be available to supply the SMA contractors when the order size justified the manufacture.

The selection of this Cooma rock for testing was not just out of convenience, but as Dan Moye said, it was deliberately chosen "because the rock appears quite similar in mineralogical composition to the granite Type I at T.1 Power Station and the rock along T.2 tunnels and T.2 Power Station (except it was) quite different in regard to its jointing."[10]

SLIDE 28 - DAVID LAFEBER # 4105

Of all the ideas to have the most psychological influence on the rock bolt skeptics found everywhere, it was those of David Lafeber, the petrology geologist who "takes the cake" working under Dan Moye[11]. He devised a model in the first rush of analysis that brought a wry smile to everyone who saw it.

SLIDE 29 - UP-TURNED BUCKET DEMONSTRATION

I refer to the upturned bucket model, filled with fine crushed rock and 40 model Rock Bolts holding the lot in place. No mirrors, no secret wires, no glue; it was authentic and could even support 40lb (or 18kg) weight from the central bolt. This unit was kept on display in the Engineering Geology Laboratory for its VIP visitors and the public tours going through the Labs constantly. ® bucket, ® model bolts

SLIDE 30 - ORAL HISTORY COMMENT BY ERIC WARRELL

An amusing story goes with this bucket model, relating to the visit by the Duke of Edinburgh at the time of the Melbourne Olympics in 1956. The Duke was being conducted by the Scientific Services Lab's deputy head, Eric Warrell. Hear his own account of the incident from the Oral History tape[18]: *Dan Moye offered to undo one bolt for the skeptical Duke - yes, and on doing so the whole bucket contents fell to the ground, much to the Duke's immediate satisfaction.*

SLIDE 31 - LAURIE ALEXANDER # 4083
The physicist, Laurie Alexander, became a world leading researcher into rock pressure and the measurement of it[19]. To know what was the forces operating around an underground excavation was vital if the rock bolt was to be part of the restraining force to stop the tunnel collapsing on itself over time. He worked initially in the first underground station, Tumut 1, or T.1. ®

SLIDE 32 - FLAT JACK SET-UP: FRONT VIEW
Here is an illustration of the method he took and refined to produce accurate results[19]. He put markers either side of a point where a slot was to be cut in the tunnel rock. Then after drilling out the slot to take a hydraulic flat jack, like this ®, the marker points move toward each other under the natural rock pressure. He could follow how the spacing of the markers changed over time and how much pressure was needed in the jack, cemented into the slot, to expanded the slot back with the jack to give the markers their original spacing.

SLIDE 33 - FLAT JACK SET-UP: CUT-AWAY VIEW
A side, or cut-away, view of the same test set up for measuring in situ rock pressure. The results amazed all ; the horizontal pressure often exceeded the vertical gravity pressure in tunnel excavations. Such a pressure could cause the collapse of the tunnel if it were not restrained by Rock Bolts or some other method. The knowledge of rock mechanics was essential for good engineering design so that the job was done correctly the first time.

SLIDE 34 - RUDI BELIN # 7278
Another Physicist from Engineering Physics Laboratory was Rudi Belin. His interest was in measuring the affect of putting pressure from a plate against the underground rock, including the affect that pattern Rock Bolts had on the measurements at varying distances from the pressure plate[1]. He worked in the small exploratory tunnel for the second underground station, T.2. As the main cavern was being excavated, this steeply sloping tunnel (34°) was used to draw fresh air into the main area of activity, that exhausted via the main access and spoil haulage road. It was, therefore, a steep, cold and draughty environment to set up his field laboratory. But in spite of these and many other hardships, very accurate results were obtained.

SLIDE 35 - RUDI'S EXPERIMENTAL SET-UP
Here is a photo of his test rig in a tunnel 2.44m diameter (8ft), with pressure plates in two directions at right angles[1]. He had to scrounge to construct his own cart and winch to travel up and down the sloping tunnel, but had the time to plant and harvest beautiful tomatoes that he had planted and grown by the end of his experiments[20] that summer in the remote narrow Tumut river flat that gave access to his tunnel.

SLIDE 36 - SPECIAL ROCK BOLTS TO MEASURE TUNNEL SHRINKAGE
One final measuring tool was to watch how an anchored Rock Bolt moved over time. In this illustration all the Rock Bolts have a hollow centre in which a rigid wire emanates from a fixed position at the far end. Thus it was possible to measure the shrinkage that may occur in a tunnel over time, depending on how deep the Rock Bolts were applied with their own external fixtures, ie the central wire remained free through the external fixture[19]. ®

SLIDE 37 - MAKING THE ROCK BOLTS PERMANENT (dot points)

The last hurdle was to make the Rock Bolt a permanent item in the reinforcement of exposed rock in a tunnel.

- Serious consideration was given to external painting[7], and epoxy resin was tried. The idea to use stainless steel in the bolts was rejected because such steel was less ductile and expensive;
- using the proprietary "Perfo" Rock Bolt from Sweden[21] but neither of these satisfied the SMA perfectionists. It happened that a verbal report came from one of the returning SMA engineers with USBR where a laboratory batch plant had been refurbished;
- aluminium powder with cement would cause the mix to expand, so ensuring all the steel of the Rock Bolt would become encapsulated[12]. This was the perfect solution; four parts per thousand for aluminium powder to neat cement, and 400 parts of water (by weight).

SLIDE 38 - EUREKA: GROUTING THE BOLTS Don #1056, Frank #7351 (dot points)

- Engineer Don Kennard tested various mixes in the laboratory and determined the right formula. It was essential that the expansion to the grout was just sufficient to counteract the shrinkage as it cured, but not enough to make the grout flocculent and therefore weak and porous[22].
- The next need was to completely fill the hole for the Rock Bolt without releasing the bolt tension. Engineer Frank Navin invented a batching plant fitted for injection the mix into the air space surrounding the Rock Bolt in its hole to cover the number of Rock Bolts that may be required in a tunnel advance. This was all done in readiness for the second underground power station project, T.2, under construction early in 1959.

The greatest single difficulty reported in this last phase of the development was a collar to seal the protruding bolt as it leaves its hole. Ultimately a cast rubber cone fulfilled the task ®.
In 1961, Prof Leech and Ted Pender presented a paper in Paris, France[22], on this final phase to make the Rock Bolt a permanent feature of tunnel support.

SLIDE 39 - IMPLEMENTION UNDERGROUND

Whilst the Upper Tumut tunnels drawings and specifications had been produced under supervision and advice to SMA personnel from the USA Bureau of Reclamation, the Tumut 1 power station engineering was taken up by the SMA entirely[4].
Incidentally, the USBR had been set-up in a similar way some 15 years earlier by President Roosevelt.

SLIDE 40 - T.1 CAVERN

This is the T.1 cavern: about a cricket pitch wide, two cricket pitches high and about 5 cricket pitches long. Note the concrete arches in the roof of the cavern. It was just as important to have Rock Bolts in the walls because of the high horizontal pressures from the rock behind them. The Resident Engineer, John R Rae was author of one-part of the five-part Report[11] into Rock Bolting organised by Dan Moye in July 1956 at the behest of Associate Commissioner, Tom Lang. The power station was completed in 1959 and remains fully operational.

SLIDE 41 - T.1 CAVERN ROOF SUPPORT

Here we see the T.1 cavern roof. Note the big structure required for casting the concrete arches. In the foreground you can see the black spots of the fixings for the Rock Bolts.
The French consortium Contractor doing T1 was very inclined to ignore instructions of his contract. But once Tom Lang was satisfied that the improved understanding of Rock Bolting

would prevent another rock collapse, they asked the Contractor to change from relying on temporary props in spite of the 40 ton collapse they had experienced many months earlier. The Contractor would not agree! So Tom Lang ordered that they be required of the Contract and that any risk consequences be covered by SMA[4]. This was a bold step! Consequently, the supplementary transformer cavern with a span of almost the same span as the main cavern, used pattern Rock Bolting with concrete ribs. Within a month the Contractor was convinced and their new method of support was published an article in their French technical news[16].

SLIDE 42 - INITIAL FORM OF ROCK BOLT

The type of Rock Bolt used in the early days of T.1 is shown in this picture[15]. A wedge put into a slit at the end of the bolt spreads the sides on reaching the bottom of hole when the bolt hammered in. ® WEDGE

About 10 of these were in the 40ton block of rock that fell from the roof. The head geologist for the Upper Tumut site, Ken Sharp, just happened to be on leave for his marriage at the time. The very first thing that greeted his return to Cabramurra with his bride was the rock fall news! Not enough engineering knowledge had been gained in the use of Rock Bolts in such a tricky intersecting zone of two faults crossing this section of the exposed cavern roof. Further rock movement did occur in spite of using these early style of Rock Bolts, but properly anchored. What could be achieved with Rock Bolts, laid in a pattern, was to be learnt in the SMA laboratory tests over the next few months[5].

SLIDE 43 - DAVE STAPLEDON #2194

Dave Stapledon was a pioneer on-site geologist for the second power station underground, T.2. Dave wrote his Master of Science thesis in 1962 based on his work in T.2, of similar size to T.1. Following the 40ton rock fall in T.1, both he and Ken Sharp went on an overseas tour together. They were looking specifically at Rock Bolt expansion shell anchorages that may have been on the market[13].

See the sample.®

At this early stage they were thinking and looking at overcoming the problems that would be faced to surround the bolt with a mortar within its hole.

The same expertise in geological information allowed a greater use of fully grouted Rock Bolts in T.2[23]. There were no failures of the rock support; better speeds of tunnelling, better economics of tunnelling, and improved safety of tunnelling were achieved.

Most of the Rock Bolts in the T.2 project were expansion shell type and set into their holes as a permanent system with cement mortar. 5,220 Rock Bolts were installed in the main cavern roof. Between two major tunnels that together amounted to 31km, and the whole of the T.2 Project, 40,000 rock bolts had been grouted into place within three years of the rock fall in T.1.

SLIDE 44 - T.2 HEADRACE TUNNEL FACE AT CONSTRUCTION

This is my photo in Tumut 2 headrace tunnel, taken in January in 1960. Note the miners drilling at three levels, one above the other on the "Jumbo". Each tunnel advance was about 4 metres. It was a congested work environment, noisy, high humidity and visibility was limited. There was great competition between the three mining shifts working through the 24 hour day, and also between different tunnelling projects. Many tunnelling records in hard rock kept on being broken. The bonus money for the miner-drillers was good!

Using pneumatic hammer drills, the holes for the explosives in the face and for the Rock Bolts to be placed above and around, between 5 and 10 metres from the face, were assigned to individual miner-drillers. The SMA instruction was to place the permanent Rock Bolts within a time limit of five hours of the blasting of the new face in order to arrest rock movement into the tunnel.

SLIDE 45 - STOYAN ROGLEFF # 2294

Stoyan Rogleff was typical of the engineers on site at T.2 who had the prime task of supervising the tunnelling contractor's work. Many things needed to be satisfied and disputes resolved. Prior to the SMA work there was little published information on working in hard jointed rock and the techniques for installation. Now there were far more detailed instructions in the Contract and for the SMA inspectors than available for T.1[24]. The Contract payments were made on the basis of a pricing schedule for each rock bolt and whether grouted in and this was a regular monthly chore between the SMA and the Contractor's tunnelling boss.

Not only were there issues directly with contract personnel but with Department of Labour and Industry inspectors who were, on occasions, manipulated by contract miners themselves for circumventing the instructed work. The NSW Department of Works rule book did not envisage enormous heights of ground above the tunnel, caverns of huge dimensions, nor hard rock - having coastal urban tunnels and the acknowledged text, "Proctor and White", that envisaged the use sub-dividing personnel barriers for working in large diameter shafts and of the use of steel support structures - not Rock Bolts! So Ted Pender took up the task and drafted a policy document for DLI inspectors, designed to get them on the right track[25,26]!

Many SMA personnel were intimately involved with the transition to implementing changed tunnelling practices; ranging from the Resident Engineer for T.2 Project, Bob Paton, to major contributor in the supervising engineer role in Peter A Ellwood, and the most notable of the technician inspectors, James Murray. On the other major tunnels being mined at the same time were (1) for Tooma-Tumut: Walter Hartwig, Resident Engineer, assisted by Engineer Doug Price and geologist David H Probert; and (2) Murrumbidgee-Eucumbene: A Ross McIntyre, Resident Engineer, assisted by Engineer Richard (Dick) H Mattner and geologist W R P Boucant.

Later tunnels connecting lake Eucumbene via Snowy River at Island Bend to the Geehi Reservior in the Murray River catchment all utilised the final form of the SMA era Rock Bolt.

SLIDE 46 - T.2 HEADRACE ON REST DAY AT CONSTRUCTION

Only on a rest day was the atmosphere so clear inside a tunnel. I took this photo in January 1960 at the transition from the T.2 headrace tunnel into two descending tunnels to the power station, some 225 metres below. See the white markings where the Rock Bolts have been installed. All of these water passages were given a skin of concrete later in order to avoid any chance of any rock wash-out that would damage the water turbines.

SLIDE 47 - EXPANDING ANCHOR ROCK BOLT STYLES

There was a very rapid transition in the latter stages of T.1 to move away from the wedge anchored Rock Bolt to an expanding shell anchored type. Here you see just three of the typed that were in use[15], just different at the inner anchor end. ® SEE SAMPLE ANCHORS.

The branch cavern for the seven large 330kV transformers of T.1 had the roof fully and permanently supported by these types of Rock Bolts with no reliance on concrete arched beams; such was the rapid transition of tunnel support practice.

What came later was the encapsulation of the Rock Bolt in cement and working out a collar to seal around the bolt under the nut and how to ensure the cement went right to the embedded end, up to five metres deep, especially when vertically overhead.

SLIDE 48 - FINAL FORM OF S.M.A. ROCK BOLT

Just a few more refinements came to finalise the form of the Rock Bolt that developed in the SMA era. Let me show you, in review, the sequence for installing the Rock Bolt.

SLIDE 49 - DIAGRAM (1) HOLE
First a hole is drilled in the exposed rock, about 42mm diameter and of an uncritical maximum length required for the Rock Bolt, whose chosen length was according to the rock condition.

SLIDE 50 - DIAGRAM (2) INSERT IN HOLE
The bolt with and expanding anchor is then inserted into the hole with a driving cap screwed over the outer thread and given an initial turn to engage the anchor with the wall of the hole.

SLIDE 51 - DIAGRAM (3) SURFACE FIXING
Applying at collar to seal the bolt in the hole, and using a domed surface bearing face plate and a hemispherical washer[27] (to accommodate a non-perpendicular rock face to the bolt), the turning nut would develop a taught bolt right to its elastic limit by virtue of the set spanner torque applied to the nut. Where hollow bolts were supplied it was ideal, so that cement grout could be fed via a short tube through the face plate and collar until it was seen to expel down the centre of the bolt. Thus, all the space around the full length of the bolt would become full of mortar. When hollow bolts were not available, a separate cement injection tube was put in right to the anchor end and a separate venting tube came out through the face plate.

SLIDE 52 - DIAGRAM (4) EMBEDDING ROCKBOLT IN GROUT
Under pressure, the cement mortar or grout was forced to the end of the Rock Bolt. You knew when the hole was full by observing mortar coming out of the air egress tube. It also meant that the rough sides of the pneumatically bored hole and the fractures in the rock were all cemented together as one with the Rock Bolt. Within a few days the cement was fully set, creating a firm bond between Rock Bolt and the surrounding rock.

SLIDE 53 - EXPOSING THE HISTORY
I share with you some of the rich sources of information I have used to put together this story tonight, as well as my future hopes in "exposing the history".

SLIDE 54 - SNOWY HYDRO LIMITED'S INFORMATION & EDUCATION CENTRE
No neat way exists at the heritage site itself to tell the whole story. It needs places like this, the Snowy Hydro Limited Information and Education Centre, just up the road, to display those easily "lifted" Rock Bolting components and its written and photographic story.

SLIDE 55 - SNOWY HYDRO LIMITED'S INFO CENTRE FEATURED
Here there is an excellent education centre for the next generation to appreciate how the Snowy Mountains Scheme was achieved for our Nation, and is still serving its original purpose of supplying water to the inland streams of the Murray-Darling basin.

SLIDE 56 - NATIONAL LIBRARY
I told you earlier that I found a "gold mine" of information. It was the personal papers of D G Moye that were deposited in the National Library of Australia, Manuscript Section, located on the shores of Lake Burley Griffin, Canberra.

SLIDE 57 - WBM RESEARCHING AT NLA
These papers were put there by Dan's brother after both Dan and his wife were killed in a car accident in mid 1970s.

SLIDE 58 - NATIONAL ARCHIVES OF AUSTRALIA

National Archives of Australia holds the personal records of those who worked on the Snowy Mountains Scheme. Here you see their beautiful repository in Canberra, in the parliamentary triangle.

SLIDE 59 - AUSTRALIAN NATIONAL MUSEUM

Under the futuristic design of the Australian National Museum, again on the shores of Lake Burley Griffin, , Acton Peninsular, Canberra, are held samples of the Rock Bolts as they developed in the SMA era. These have only recently been collected (by the senior curator, Matthew Higgins, who undertook most of the Snowy Mountains Scheme Oral History Project, 1999) as the direct result of Engineers Australia, Monaro Group, submitting their application for State recognition of the Rock Bolt testing site.

SLIDE 60 - WHAT OF OUR ENGINEERING HERITAGE

What inspiration comes from our engineering heritage?
Heritage is of no value if it is disregarded and disrespected.
But heritage that is worthy is that which is creative for the good of society's well being, using all the wisdom and skills that God has imbued in mankind. It is a minute copy of Almighty God's creative and beneficial works.

1. **Heritage anchors our own lives personally through our forebears and in our culture.**
2. **Heritage inspires our striving against those destructive and futile ambitions that capture us.**
3. **Heritage encourages us to use our gifts as service to mankind to emulate the goodness of God in whose image we are. It ought to lead today's generation to emulate our forebear's achievements for the needs and wellbeing of today's society.**

SLIDE 61 - TUMUT POND DAM

Here at the magnificent concrete arch dam on the Tumut River, head-pond to the Upper Tumut hydro station of T1, there is a memorial plaque to Daniel George Moye, placed in 1993.

SLIDE 62 - MEMORIAL TO DAN MOYE

It reads[28], ...Daniel George Moye and his team of geologists who, in close collaboration with the engineers, contributed effectively to the successful completion of the Snowy Mountains Hydro-electric Scheme 1949-1974 and thereby established the profession of engineering geology in Australia. Geological field investigations for the Scheme commenced at Tumut Pond in February 1950.
The idea to have this plaque came from Professor Eric Rudd, who had been a member of the international advisory panel for the Scheme, as well as Professor of Economic Geology at Adelaide University. Dan Moye's daughter, Barbara Wing, was in attendance at its unveiling.

SLIDE 63 - CAREERS MADE IN ROCK MECHANICS

Here is a list of those who made successful careers in rock mechanics from their association with Snowy Mountains Scheme activity[2] :
D G Moye[29]; J C Jaeger; L A Endersbee; C C Wood; D H Stapledon; E A Rudd; D Labefer; G Worotnicki; L G Alexander.
Rock Bolting has continued to develop and be used in more economic ways than what was the final outcome of their development for the Snowy Mountains Scheme. It is for others to say if there has been a diminuation of their reliability or a loss of skill in the exercise of this discipline.

SLIDE 64 - ENGINEERING HOUSE

I conclude with this view of Engineering House, National Circuit, Barton, ACT, on which I have written the calling of the engineering fraternity. It is expressed this way in the Code of Ethics: "Engineering is a creative process. It involves the development and application of engineering science through the management of engineering works".

What I have described to you tonight is a great example of this endeavour for the benefit of society and the wellbeing of mankind. A USA researcher, Dr Paul Anderson, said in 2006, "a culture that would rather be entertained than be engaged in innovation will not continue to be an economic power house."

It was Lance Endersbee in 1969, as a member of staff of the friendly rival organisation the Hydro-Electric Commission of Tasmania, who said, it was "the people involved, as it were by their efforts, that the Snowy story is so notable in the history of Australian engineering. ... It was inevitable that some would seek challenges elsewhere ... in engineering throughout the world still with the Snowy ... enthusiasm".

I say, let it happen again somewhere, addressing other challenges, for today's generation!

Thank you.

SLIDE 65 - TITLE SLIDE

I invite people here who have a connection to the heritage I have spoken about tonight, and who are interested in recording that historical connection, to list their name on the sheet on the table before you displaying the Rock Bolt samples.
An area that is particularly missing in Oral History is that of the especially trained inspectors. From the Oral History by Ross McIntyre[30], who accompanied Prof. Leech around the country recruiting such, people were drawn from all avenues of life, taxi drivers, musicians, etc , to be trained for the SMA tunnelling inspector's role for the integrity of the Contractor's work in Rock Bolting.

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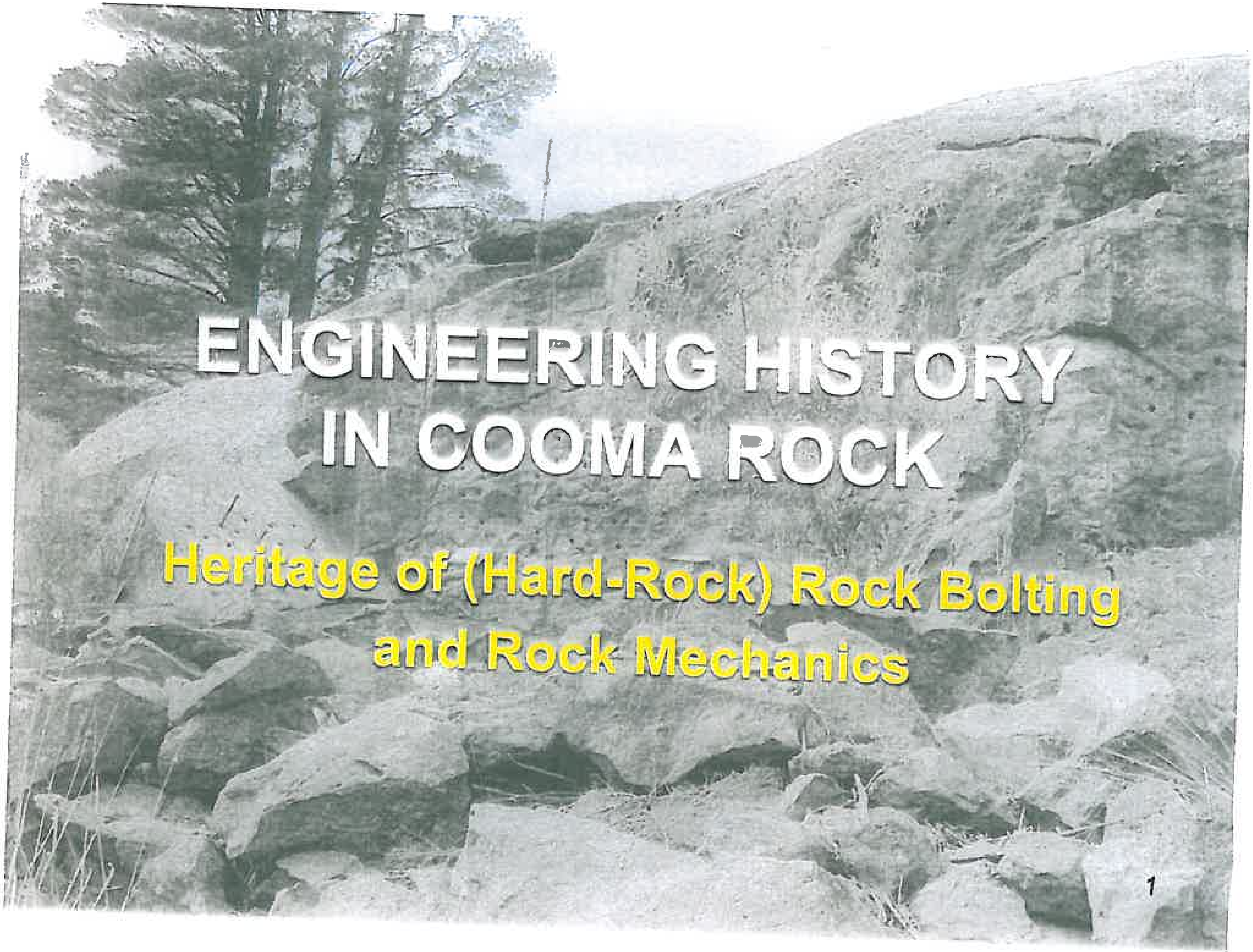
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IN COOMA ROCK
Heritage of (Hard-Rock) Rock Bolting
and Rock Mechanics
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ENGINEERING HISTORY
IN COOMA ROCK
Heritage of (Hard-Rock) Rock Bolting
and Rock Mechanics

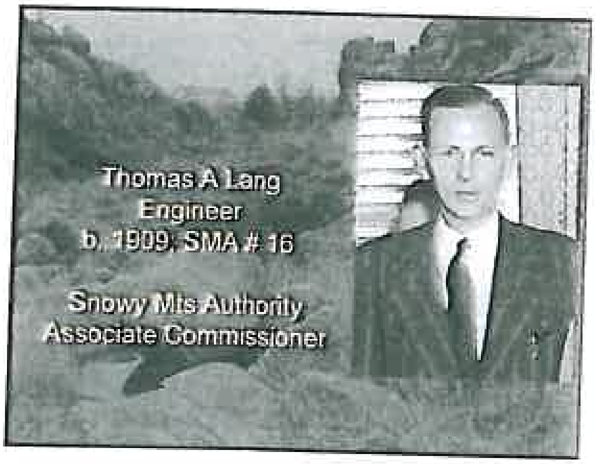

INTRODUCTION

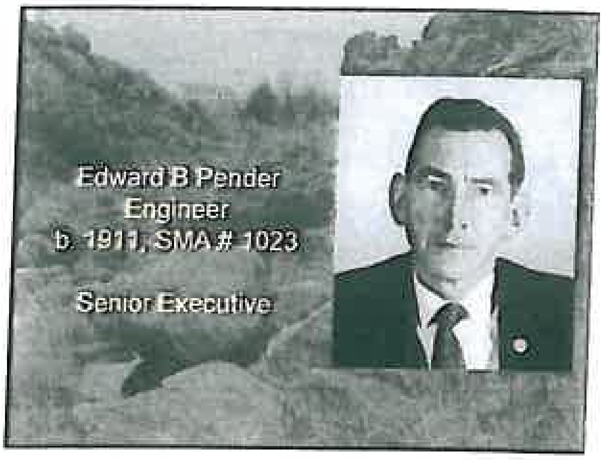
OUTLINE

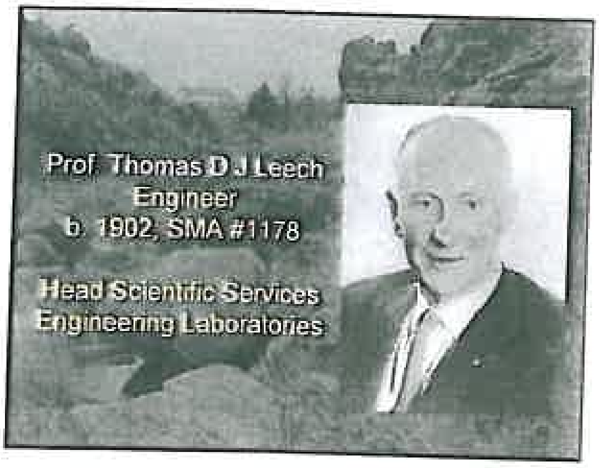
- Historical Setting
- Research and Development
- Implementation Underground
- Final Form of S.M.A. era Rock Bolt
- Exposing the History
- What of Engineering Heritage

HISTORICAL SETTING

- Collapse of 40ton from roof of cavern
- Rock bolts usage for prior 50years
- Commitment in leadership



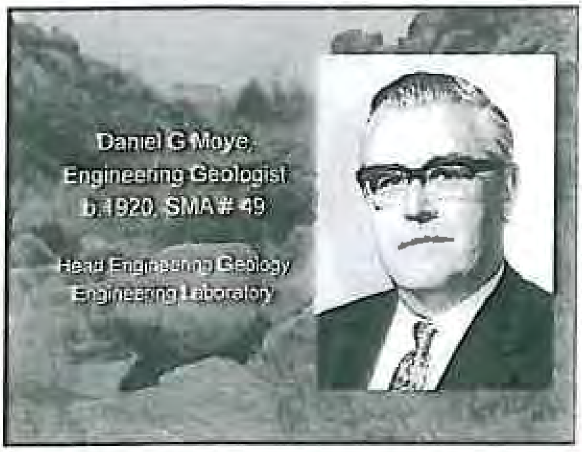





David Anderson
Engineer
b.1928, SMA # 1180
Supervisor, all Laboratories


RESEARCH AND
DEVELOPMENT


RESEARCH AND
DEVELOPMENT
• The mix of disciplines
• Experimentation with Rock Bolts
• A permanent system


Daniel G Moye,
Engineering Geologist
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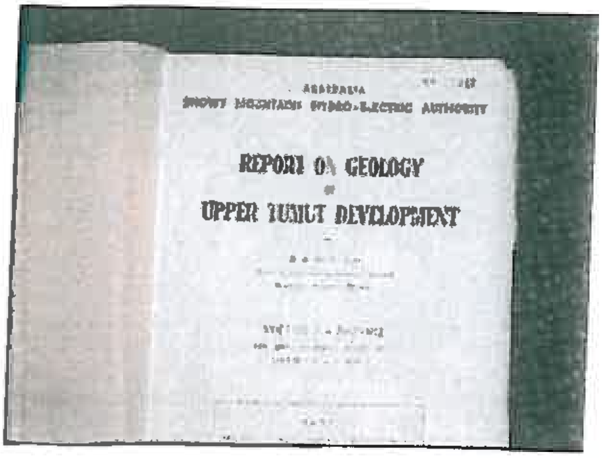
Engineering Laboratory


Clive C Wood
Engineer & Geologist
b 1927, SMA # 2022
Site Investigations &
Rock Bolt Testing


Kenneth R Sharp
Geologist
b. 1927, SMA # 1026
Tumut 1 Project
Engineering Geologist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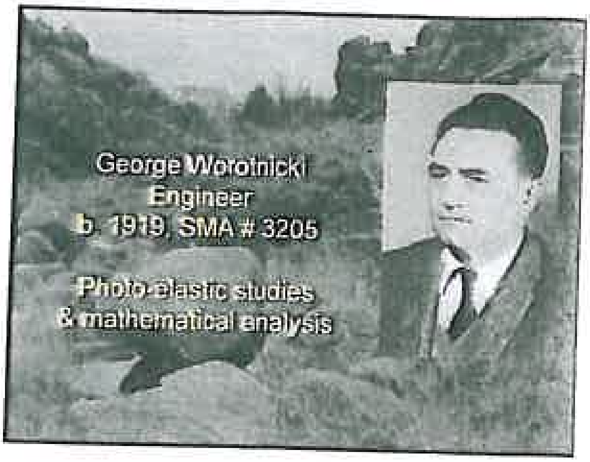
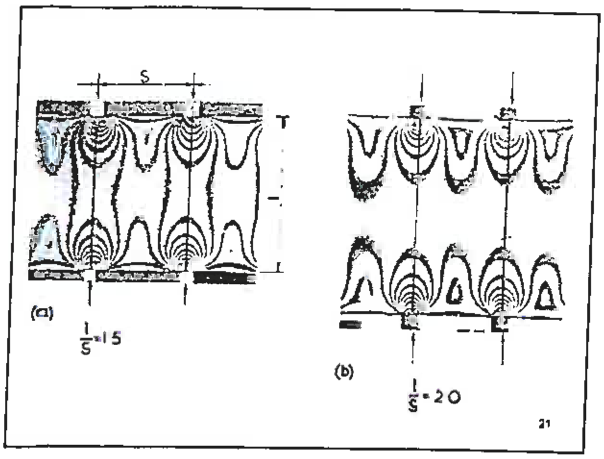

George Worotnicki
Engineer
b. 1919, SMA # 3205
Photo-elastic studies
& mathematical analysis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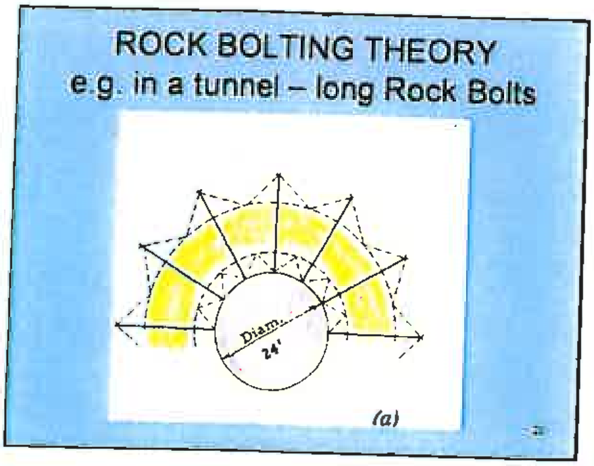
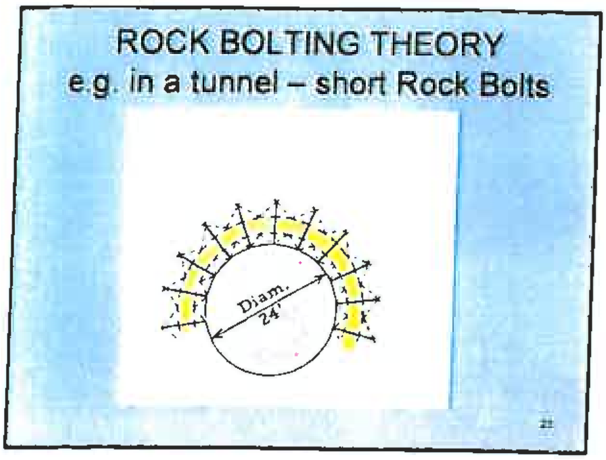
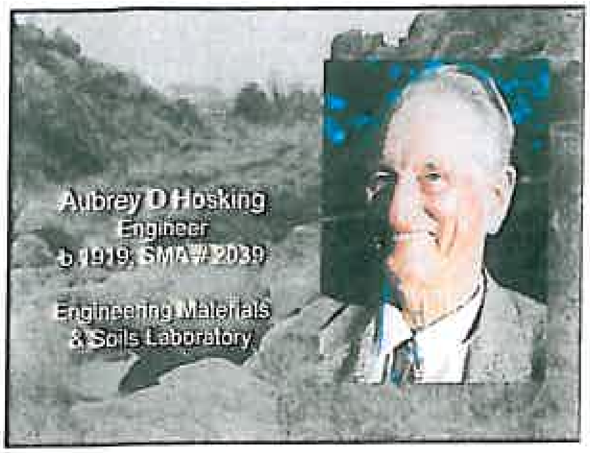
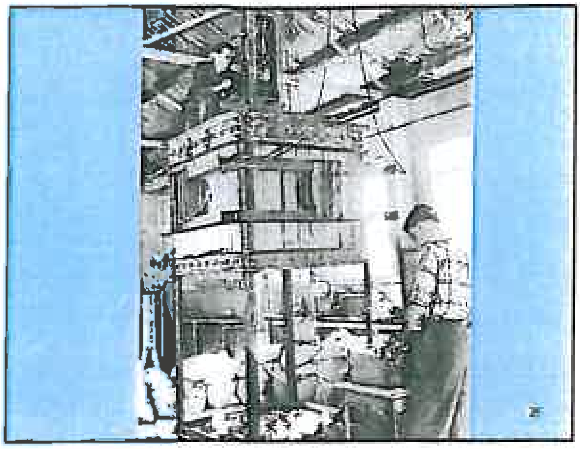
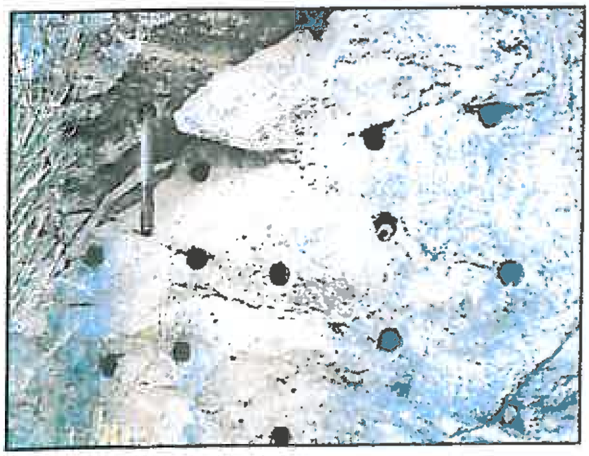

ROCK BOLTING THEORY
e.g. in a tunnel – long Rock Bolts
Diam. 24'
(a)

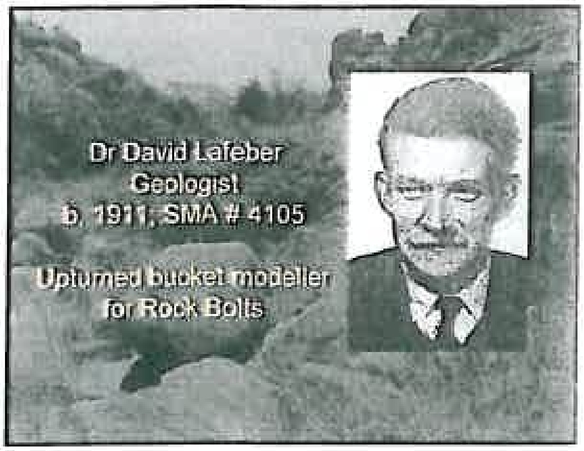

ROCK BOLTING THEORY
e.g. in a tunnel – short Rock Bolts
Diam. 24'

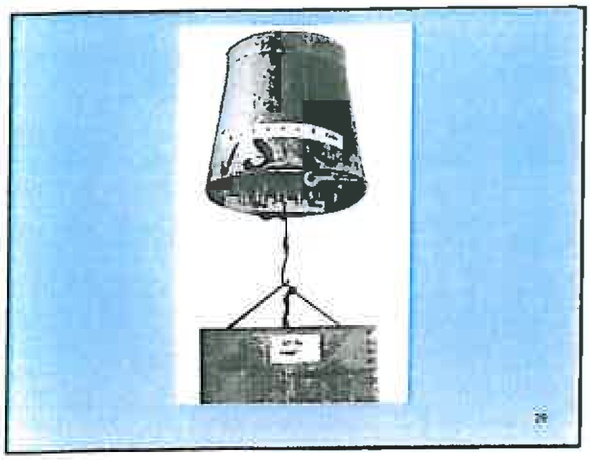

Lance A Endersbee
Engineer
b. 1925, SMA # 1034
Design & Specification

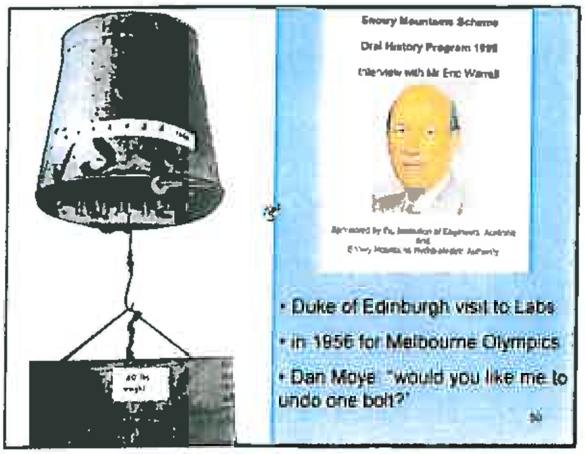

Aubrey D Hosking
Engineer
b.1919, SMA# 2039
Engineering Materials
& Soils Laboratory

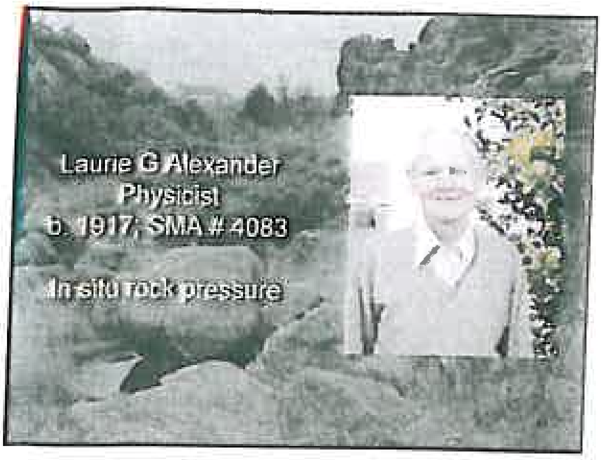


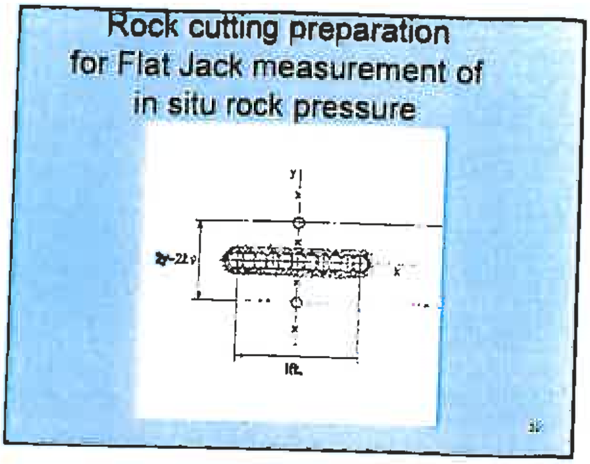


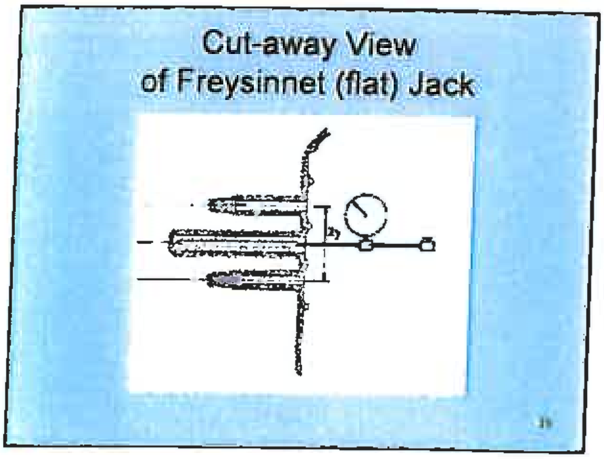

Dr David Lafeber
Geologist
b. 1911, SMA # 4105
Upturned bucket modeller
for Rock Bolts


29

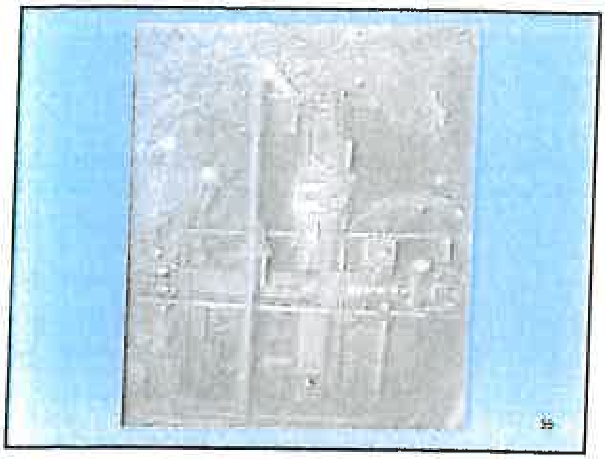

Snowy Mountains Scheme
Oral History Program
Interview with Mr Eric Warrell
• Duke of Edinburgh visit to Labs
• in 1956 for Melbourne Olympics
• Dan Moye "would you like me to undo one bolt?"
30

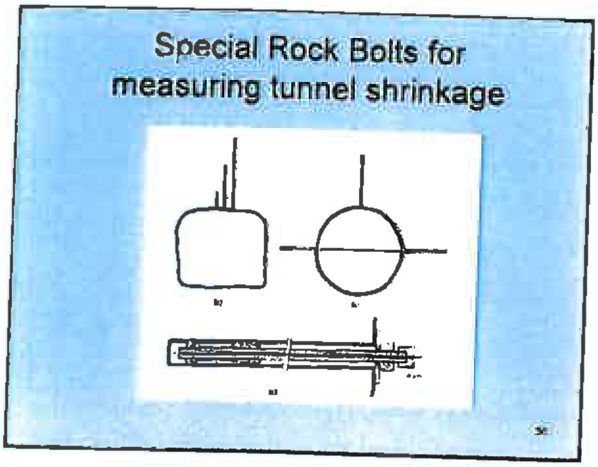

Laurie G Alexander
Physicist
b. 1917, SMA # 4083
In situ rock pressure

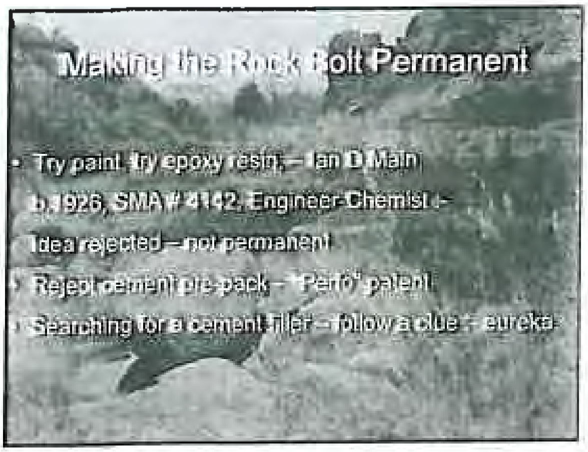

Rock cutting preparation
for Flat Jack measurement of
in situ rock pressure


Cut-away View
of Freysinnet (flat) Jack


Rudolph Belin
Physicist
b. 1920, SMA # 7278
In situ rock pressure

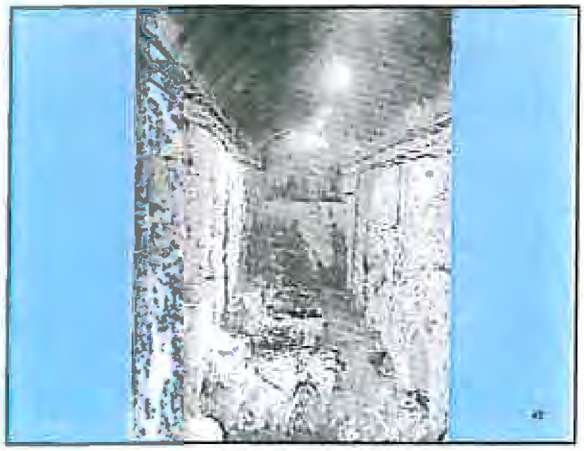


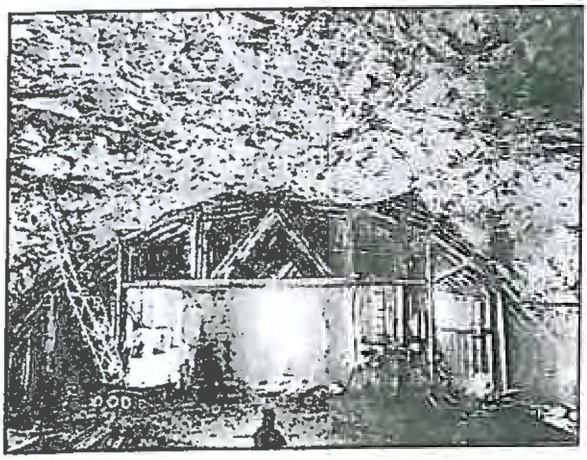

Special Rock Bolts for
measuring tunnel shrinkage

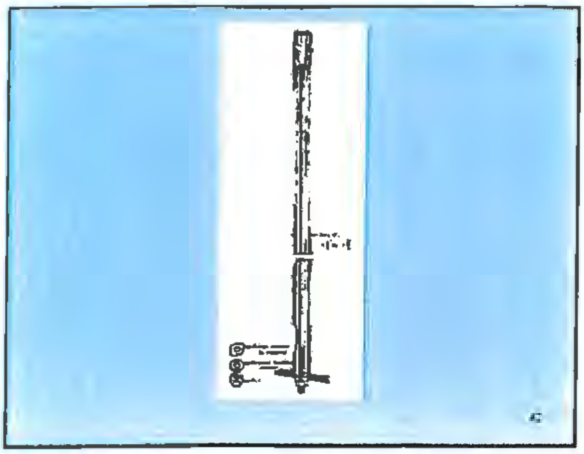

Making the Rock Bolt Permanent
Try paint, try epoxy resin, – Ian D Main
b.1926, SMA # 4142, Engineer-Chemist –
Idea rejected – not permanent
Reject cement pre-pack – "Perfo" patent
Searching for a cement filler – follow a clue – eureka

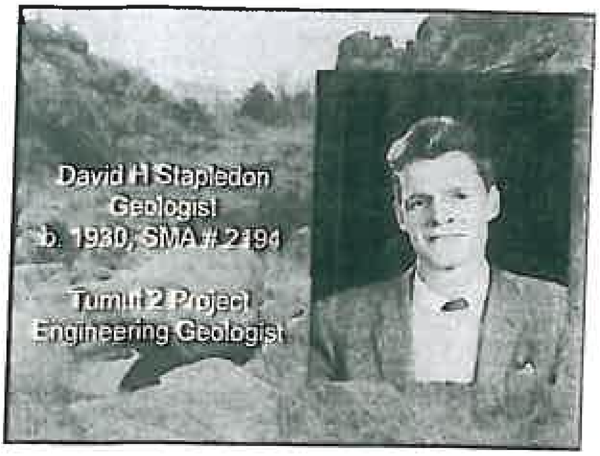

Making the Rock Bolt Permanent
Mixing formulation for cement grout –
Engineer Donald C Kennard
b. 1926, SMA # 1050
& Injection invention –
Engineer W Frank Navin
b. 1919, SMA # 7351
Method successful & Rock Bolt permanent !
38


IMPLEMENTATION
UNDERGROUND

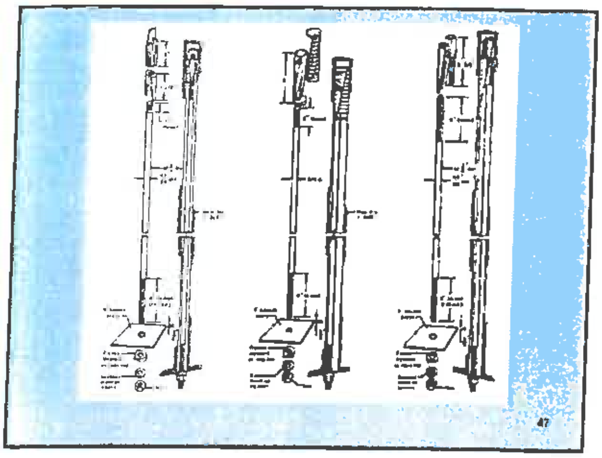


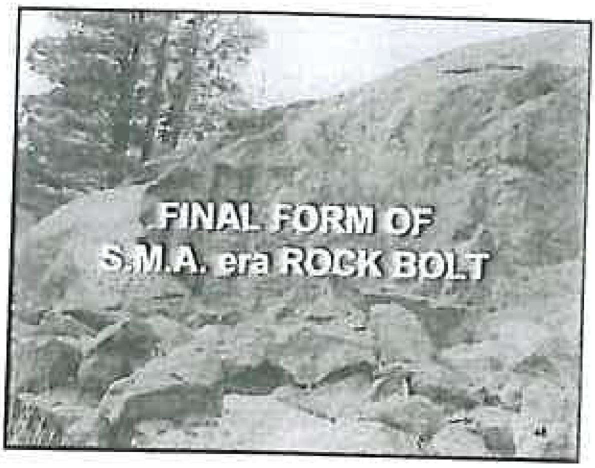


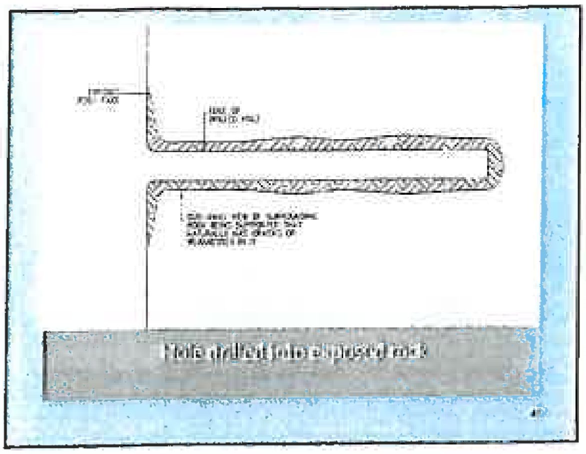


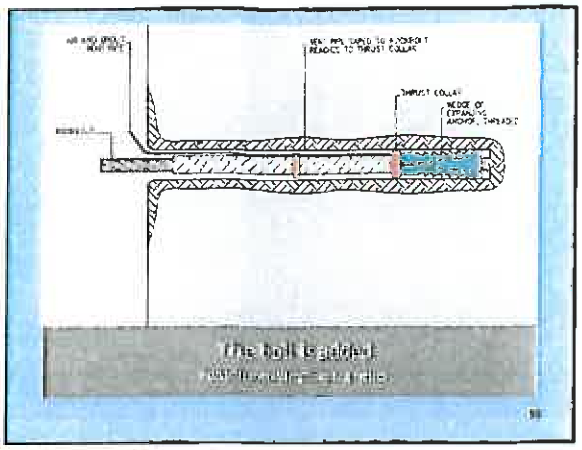

David H Stapledon
Geologist
b. 1930, SMA # 2194
Tumut 2 Project
Engineering Geologist

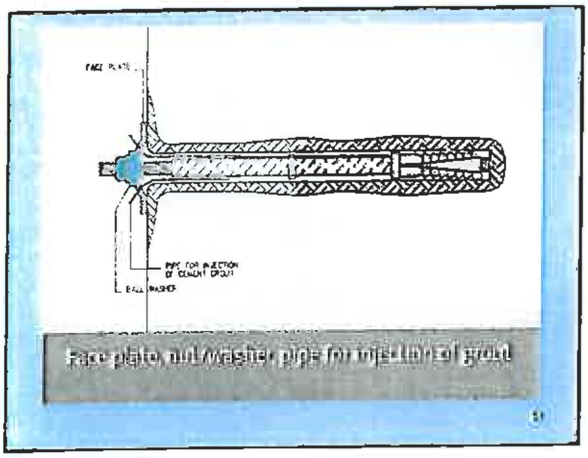

Stoyan Rogleff
Engineer
b. 1921, SMA # 2294
Site supervision

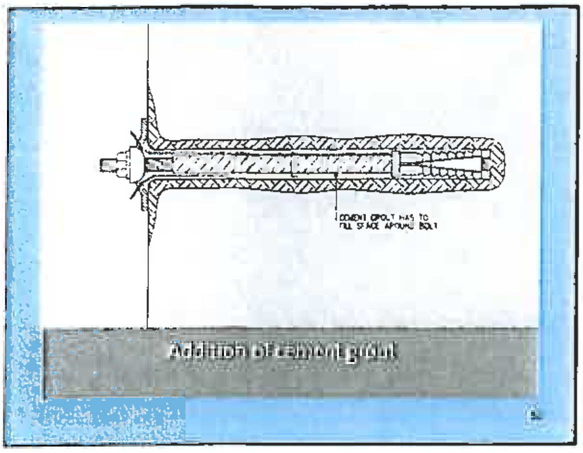


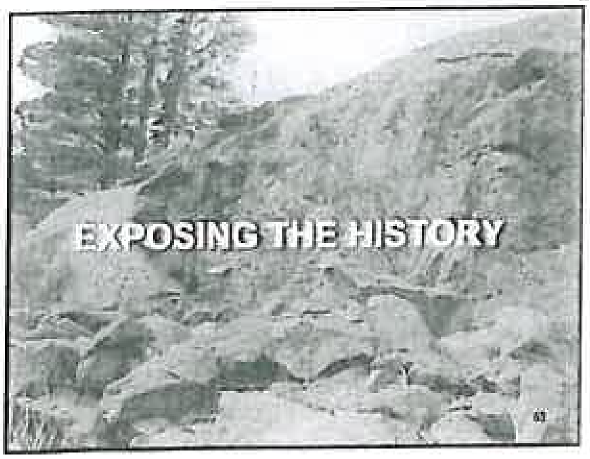

FINAL FORM OF
S.M.A. era ROCK BOLT

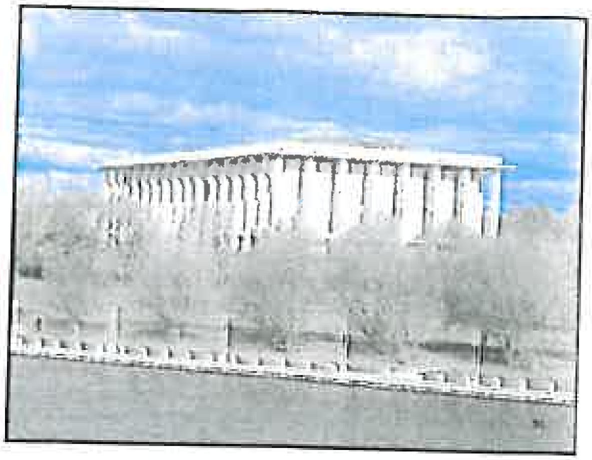

Hole drilled into exposed rock

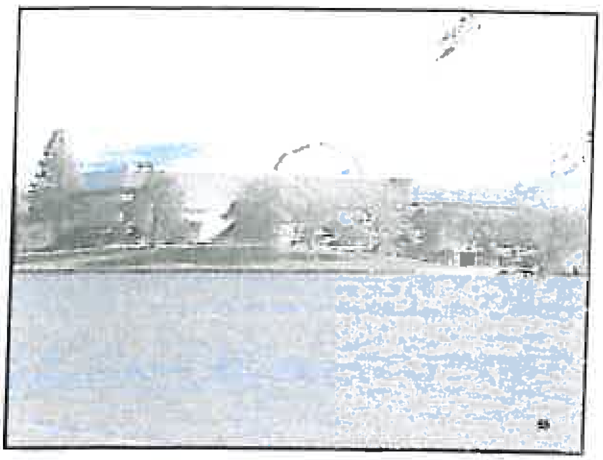

The bolt is added

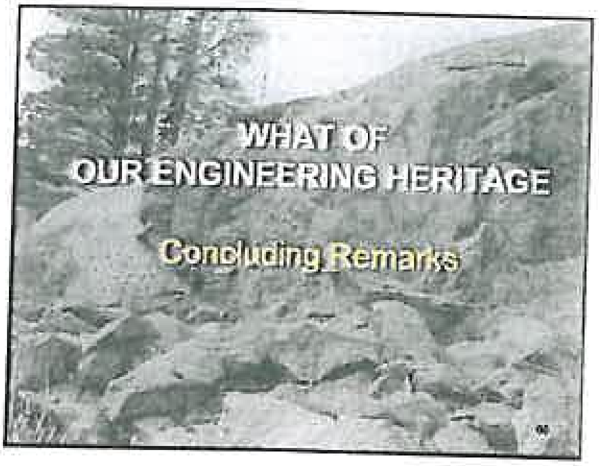

Face plate, nut/washer pipe for injection of grout

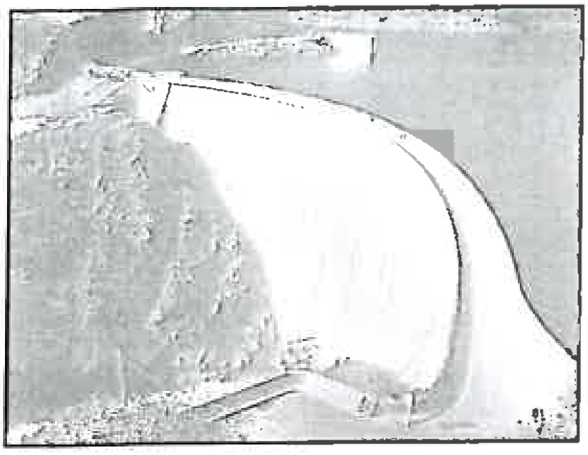

Addition of cement grout


EXPOSING THE HISTORY
53

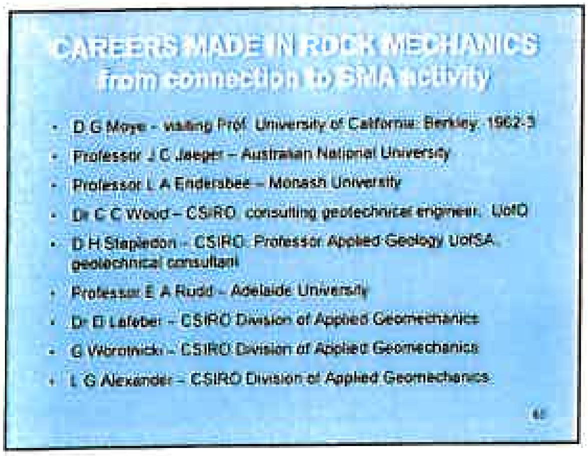





WHAT OF
OUR ENGINEERING HERITAGE
Concluding Remarks

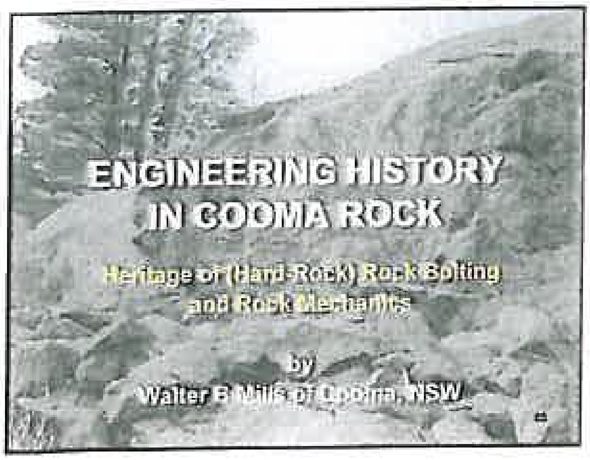


DANIEL GEORGE MOYE



CAREERS MADE IN ROCK MECHANICS
from connection to SMA activity
D G Moye – visiting Prof. University of California: Berkley. 1962-3
Professor J C Jaeger – Australian National University
Professor L A Endersbee – Monash University
Dr C C Wood – CSIRO, consulting geotechnical engineer. UofQ
D H Stapledon – CSIRO. Professor Applied Geology UofSA, geotechnical consultant
Professor E A Rudd – Adelaide University
Dr D Lafeber – CSIRO Division of Applied Geomechanics
G Worotnicki – CSIRO Division of Applied Geomechanics
L G Alexander – CSIRO Division of Applied Geomechanics

ENGINEERS
AUSTRALIA
Engineering is a creative process
It involves the development and
application of engineering science
through the management of
engineering works



ENGINEERING HISTORY
IN COOMA ROCK
Heritage of (Hard-Rock) Rock Bolting
and Rock Mechanics
by
Walter B Mills of Cooma, NSW

Engineering Heritage Committee & Australian Geomechanics Society

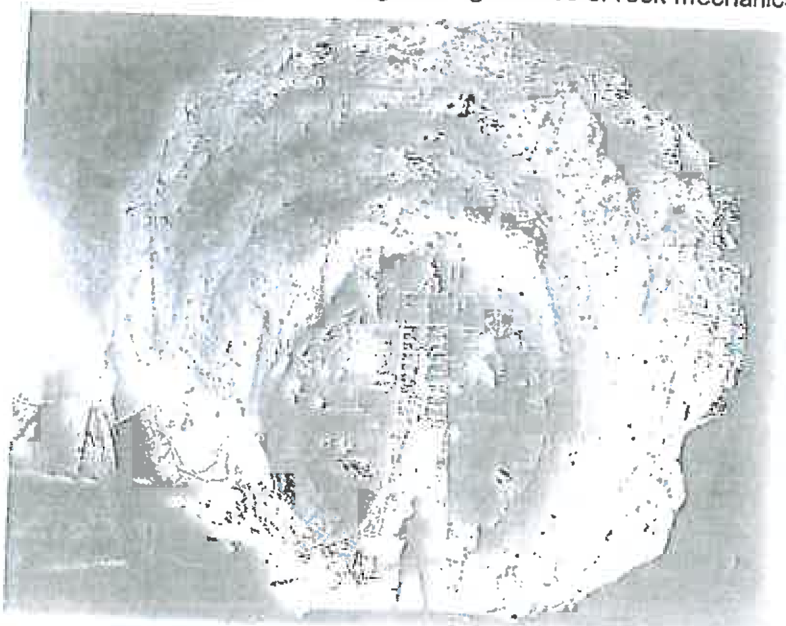
ENGINEERS AUSTRALIA
SYDNEY DIVISION

Public Lecture, Monday, 4th June 2007, Engineers Australia

Rock Bolt Heritage Site

Tumut 2 Tunnel Rock Bolting

Fifty years ago Snowy Mountains Hydro-Electric Authority experimented and developed a better method of tunneling for utility projects. It was a safer, less costly and a quicker method utilizing rock bolts. The change of practice at the time presented challenges to convince the various stakeholders. Studies by talented engineers and scientists revealed that rock bolts could arrest ultimate further weakening of disturbed rock, so replacing alternative means of support. Rock bolts revolutionized hard-rock tunneling and quickly became a world-wide practice. The development of the engineering science of rock mechanics was greatly advanced also. It has been said that the development and use of rock bolting "was probably the most significant engineering development on the Snowy Scheme. "



A few years ago the initial experimental site in Cooma's Lambie Gorge was re-discovered along with remnants of rock bolts and drill holes where testing was carried out. It is a significant site in the history of engineering. Consequently a nomination has been prepared for its placement on the State Heritage Register, and another is in preparation for its recognition as a National Engineering Landmark.

Speaker: Walter B Mills, Charted Professional Engineer of Cooma, NSW

Walter Mills has made his career in hydro-electric engineering, commencing work on the Snowy Mountains Scheme that allows management of the Snowy Mountains water. He saw first-hand the underground working for tunnels and caverns. He was part of the engineering design team; two huge power stations completely underground, and overall 130km of large tunnels. Involvement was continued with some of the same people with SMEC, consultants in water projects world-wide.

****

ENGINEERS AUSTRALIA
SYDNEY DIVISION

Engineering Heritage Committee & Australian Geomechanics Society

Public Lecture

ENGINEERING HISTORY IN COOMA ROCK

HERITAGE OF HARD-ROCK ROCK BOLTING AND ROCK MECHANICS

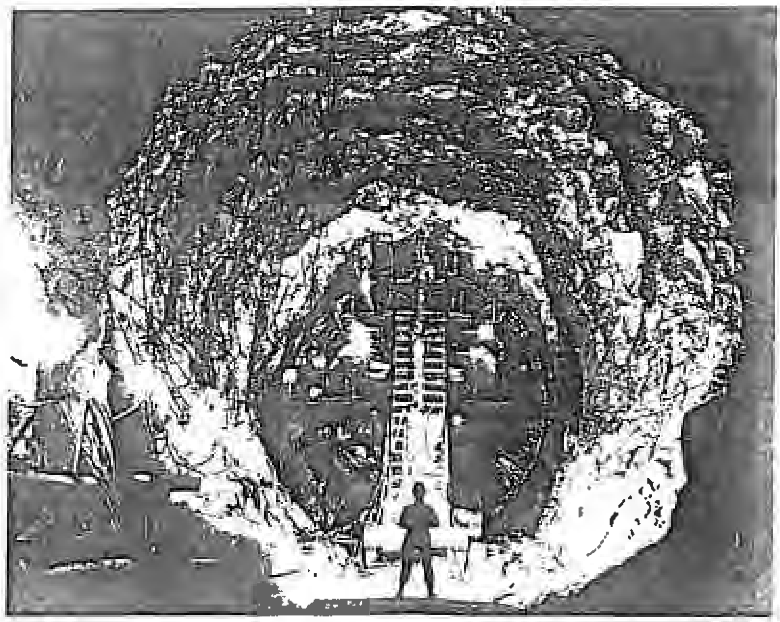
Speaker: Walter B Mills. BE (Elec.), MIEAust, CPEng, NPER

Monday, 4th June 2007

6.00pm

Engineers Australia Auditorium
Ground Floor, 8 Thomas Street, Chatswood

Fifty years ago Snowy Mountains Hydro-Electric Authority experimented and developed a better method of tunneling for utility projects. It was a safer, less costly and a quicker method utilizing rock bolts. The change of practice at the time presented challenges to convince the various stakeholders. Studies by talented engineers and scientists revealed that rock bolts could arrest ultimate further weakening of disturbed rock, so replacing alternative means of support. Rock bolts revolutionized hard-rock tunneling and quickly became a world-wide practice. The development of the engineering science of rock mechanics was greatly advanced also. It has been said that the development and use of rock bolting "was probably the most significant engineering development on the Snowy Scheme."



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All are welcome. Admission Free. Refreshments from 5.30pm.

****

ENGINEERS AUSTRALIA

Sydney Division

Monaro Country Group

As part of Engineering Week 2007, the Monaro Country Group is pleased to invite members of Engineers Australia and guests to an Ordinary Meeting on

Thursday 23 August 2007
5.15 to 6.30pm
Snowy Hydro Information and Education Centre, Cooma

Our guest speaker for the evening is **Wally Mills**, *MIEAust, CPEng*, whose presentation will be on:

"Engineering History in Cooma Rock"

The Heritage of Hard-Rock Rock Bolting and Rock Mechanics

It has been said that the development and use of rock bolting "was probably the most significant engineering development on the Snowy Scheme. " A few years ago the initial experimental site in Cooma's Lambie Gorge was re-discovered along with remnants of rock bolts and drill holes where testing was carried out. It is a significant site in the history of engineering. Consequently a nomination has been prepared for its placement on the State Heritage Register, and another is in preparation for its recognition as a National Engineering Landmark.

Wally Mills has made his career in hydro-electric engineering, commencing work on the Snowy Mountains Scheme.

Light refreshments will be served prior to the meeting.

Advance notice:

Annual Dinner – Wednesday 5 September 2007
6.30pm for 7.00pm
Venue –TBA
Presentation: "Snowy Scheme Museum"
Guests: Warren Newell (President) and Richard Phillips (Exec. Director)
EA Sydney Division

Local Chairman: David Byrne
Ph: 02 645 01750
Fax: 02 645 01799

Postal Address:
C/- Azeez Ahamat (Secretary/ Treasurer)
Snowy Hydro Ltd
PO Box 332, COOMA NSW 2630

ENGINEERS
AUSTRALIA
Canberra Division

Engineering Heritage Australia (Canberra)

Public Lecture

ENGINEERING HISTORY IN COOMA ROCK
HERITAGE OF HARD-ROCK ROCK BOLTING AND ROCK MECHANICS

Speaker: Walter B Mills. BE (Elec.), MIEAust, CPEng, NPER
Wednesday 24 October 2007 – 5.30 for 6.00pm
Engineers Australia Auditorium
Ground Floor, Engineering House, 11 National Cir, Barton ACT

Fifty years ago Snowy Mountains Hydro-Electric Authority experimented and developed a better method of tunnelling for utility projects. It was a safer, less costly and a quicker method utilizing rock bolts. The change of practice at the time presented challenges to convince the various stakeholders. Studies by talented engineers and scientists revealed that rock bolts could arrest ultimate further weakening of disturbed rock, so replacing alternative means of support. Rock bolts revolutionized hard-rock tunnelling and quickly became a world-wide practice. The development of the engineering science of rock mechanics was greatly advanced also. It has been said that the development and use of rock bolting "was probably the most significant engineering development on the Snowy Scheme. "

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Walter Mills has made his career in hydro-electric engineering, commencing work on the Snowy Mountains Scheme that allows management of the Snowy Mountains water. He saw first-hand the underground working for tunnels and caverns. He was part of the engineering design team; two huge power stations completely underground, and overall 130km of large tunnels. Involvement was continued with some of the same people with SMEC, consultants in water projects world-wide.

All are welcome. Admission Free. Refreshments from 5.30pm

For catering please RSVP to blowe@engineersaustralia.org.au or phone (02) 6273 1314.

**Engineering Heritage Committee &
Australian Geomechanics Society**

ENGINEERS AUSTRALIA Tasmania Division

Public Lecture

ENGINEERING HISTORY IN COOMA ROCK
HERITAGE OF HARD-ROCK ROCK BOLTING AND ROCK MECHANICS

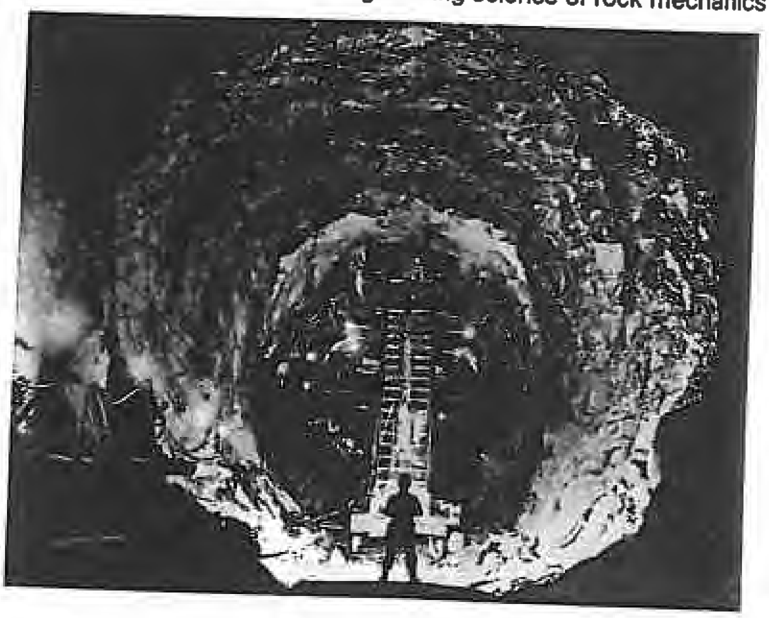
Speaker: Walter B Mills. BE (Elec.), MIEAust, CPEng, NPER

Tuesday, 30 October 2007

5.30 for 6.00pm

**Royal Engineers Building
2 Davey Street, Hobart**

Fifty years ago Snowy Mountains Hydro-Electric Authority experimented and developed a better method of tunneling for utility projects. It was a safer, less costly and a quicker method utilizing rock bolts. The change of practice at the time presented challenges to convince the various stakeholders. Studies by talented engineers and scientists revealed that rock bolts could arrest ultimate further weakening of disturbed rock, so replacing alternative means of support. Rock bolts revolutionized hard-rock tunneling and quickly became a world-wide practice. The development of the engineering science of rock mechanics was greatly advanced also. It has been said that the development and use of rock bolting "was probably the most significant engineering development on the Snowy Scheme."



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Refreshments from 5.30pm

RSVP to Catherine Reading 6234 2228 or creading@engineersaustralia.org.au

ENGINEERS
AUSTRALIA
Queensland Division

PRESS RELEASE
Townsville Local Group
Engineering History in Cooma Rock

A **presentation** will be given by Mr Wally Mills, Senior Engineer semi-retired, on **"Engineering History in Cooma Rock".** Using slides and samples, Mr Mills will present the engaging story of about a dozen Cooma based people and the circumstances that combined to allow the development of rock bolting into an engineering science. The achievement also helped established rock mechanics as an engineering discipline in it own right across the world.

The historical engineering topic has value in being told to illustrate just how the profession of engineering serves the greater good of our Australian society. It also has as well, reference to the fascinating heritage site itself in Cooma's Lambie Gorge. This site represents the huge advance in all engineering tunnelling design and practice that came about within a three to four year time span by 1960.

The Townsville Local Group is inviting members of Engineers Australia to **"Engineering History in Cooma Rock"** Tuesday 26 August 2008 at 6pm at the Mercure Inn Townsville. Refreshments provided.

For further information on the presentation **"Engineering History in Cooma Rock"** please contact Alan White on 07 4750 7000 or Mobile 0488 748 465, also please **Rsvp to Bronwyn Wood 07 4781 6327 or bwood@engineersaustralia.org.au**

Authorised by Alan White

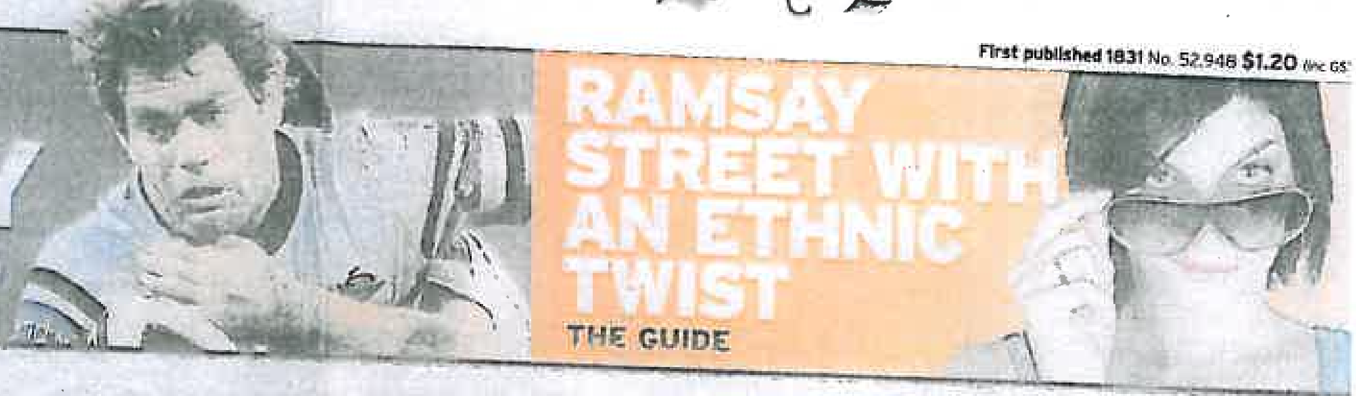
Townsville Local Group
Chairman: Alan White
Ph: 07 4750 7000
Fax: 07 4750 7077

Postal Address:
PO Box 1056,
TOWNSVILLE Qld 4810

The Sydney Morning Herald

Monday June 4, 2007

First published 1831 No. 52,948 $1.20 (inc GST)



SECRET POLL

Voters dread Costello switch

Phillip Coorey
Chief Political Correspondent

A MAJORITY of swinging voters in key NSW seats believe John Howard will hand the leadership to Peter Costello if the Government wins this year's election but

Rock star recession

Peter Garrett's quest to cut greenhouse emissions is "the recipe for a Garrett recession", the Prime Minister warned. But Peter

Welcome to the Central Coast mosh pit

Cold cases likely to stay cold, police say

Les Kennedy

TWO hundred murder cases deemed solvable are about to be sent back to local detectives – but senior police fear they will remain unsolved for years because of insufficient resources and a growing backlog of 9000 exhibits for DNA analysis.

Kings Cross police alone will be handed 37 old murder cases on top of an already heavy crime load for the 15 detectives. Seventy detectives at the Homicide Squad can normally only manage 50 to 60 cases a year.

The cases include a series of gangland killings amid suspicions they went nowhere because of corrupt police involvement.

But the Unsolved Homicide Unit, dubbed the "cold case squad", believes the 200 murders *can be solved with the aid of* modern forensic techniques such as DNA analysis of blood, saliva and hair found at crime scenes, along with fingerprints and ballistics evidence.

It chose the 200 from more than 400 unsolved murders com-

Today at

The Guide
Michael Idato and Doug Anderson preview today's TV highlights including *The Simple Life*, starring Paris Hilton and Nicole Richie.
smh.com.au/entertainment

Whale Watch
Reports and pictures on the magnificent creatures of the deep.
smh.com.au/specials/whalewatch

Set up
A sneak peek behind the scenes on the set of Baz Luhrmann's movie *Australia*.
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Battle to control fire

Nifty idea made a whole lot of difference

Steve Meacham

CALL IT a bolt of inspiration.

Fifty years ago a group of engineers working on the Snowy Mountains scheme invented a device that revolutionised man's ability to tunnel through rock.

Today, says Walter Mills, a Cooma engineer, anyone who has hung a heavy picture on a wall will be familiar with the concept of an expanding anchor bolt. Small ones can be bought from any hardware store.

But in 1947, when those engineers began experimenting with four-metre-long expanding anchor rock bolts, they were pioneers. Within a few years of trial and error they had made tunnelling through rock not only cheaper and faster, but safer.

Tonight Mr Mills, 68, will deliver a lecture in Sydney paying homage to those he calls "some of the great unsung heroes of Australian engineering".

"This was an Australian first," says Mr Mills, who joined the Snowy Mountains Hydro Electricity Authority in 1959, when the technology was already well advanced.

"They'd been using rock bolts in coalmines since the early 1900s," he said. But those bolts had been used only as a temporary measure - giving miners time to put permanent props in place.

The breakthrough at the authority's experimental site at Cooma's Lambie Gorge came when the engineers perfected expanding anchor bolts. Once drilled into the rock in precise patterns, these permanently bound the unstable rock faces exposed by blasting - without the need for time-consuming props.

Miners needed convincing that a shaft without props was safe. But once their worth was shown, rock bolts were used throughout the immense scheme, allowing two huge underground power stations and more than 130 kilometres of tunnels to be completed.

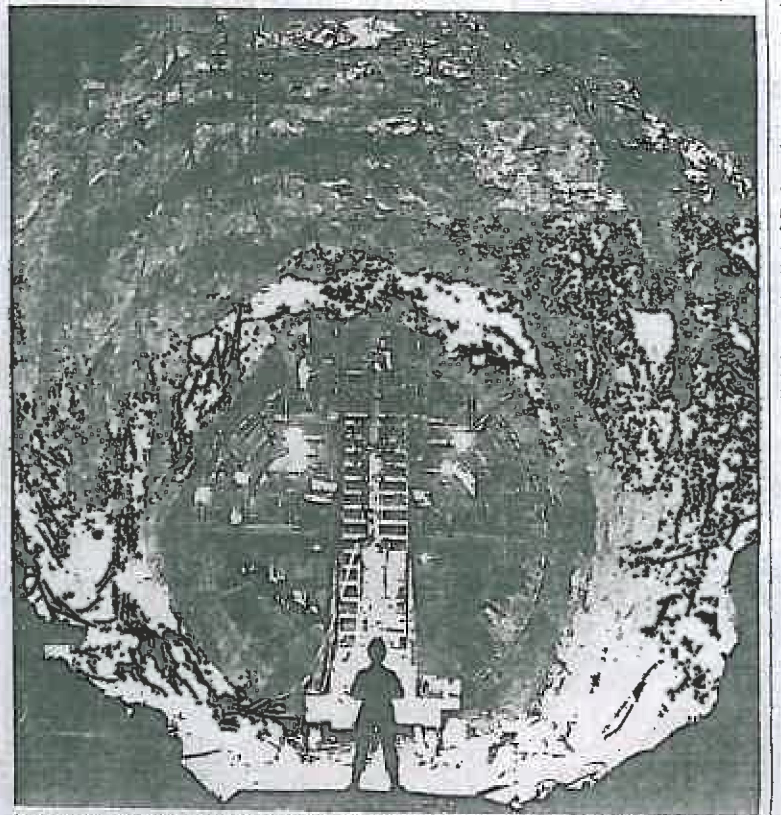
About a dozen key engineers worked on the project in Cooma alongside Daniel Moye, who headed the authority's geology engineering department. Critically, they were aided by academics - chiefly Professor John Jaeger, chair of geophysics at the Australian National University, and Professor Eric Rudd of Adelaide University.

An expert on rock mechanics, Professor Ted Brown, has said the development and use of rock bolts was "probably the most significant engineering development made on the Snowy scheme".

Soon word spread across the world, making countless tunnelling projects affordable and possible. "But it was never patented," Mr Mills says.

His lecture is intended to raise the profile of what he calls "a significant site in the history of engineering". The initial experimental site was recently rediscovered, with remnants of the rock bolts and drill holes where testing took place. Mr Mills has led a campaign to have it placed on the State Heritage Register.

Engineers Australia Auditorium, 8 Thomas Street, Chatswood, 6pm.



Props away ... the Tumut 2 Tailwater Tunnel being built in 1960. Photo courtesy of Snowy Hydro Limited

Police cool on cold cases

From Page 1

to do them on top of their existing work," a Major Crime officer told the *Herald*.

"The emphasis in local area commands now is on solving volume crime [such as break-and-enters and car thefts]; that's all commanders are interested in.

"There are on average 100 murders a year in NSW, and the Homicide Squad, with about 70 detectives, actively examines 50 to 60 of them. The rest are handled locally. So how is Kings Cross going to cope with 37?"

The state police strategy has also shifted priority in funding ...

Victims ... Georgina Watmore and Catherine Pollard.

are arrested for another crime. This is because legal problems persist, with differing state laws on the collection of DNA, as re...

the cases that will be returned to local area commands, but the cold case squad will also ask Cowra detectives to reopen investigations into the April 1987 murders of Catherine Pollard, 28, and her friend Georgina Watmore, 24. They were found bludgeoned to death in their home after a party.

Among the "solvable" Kings Cross cases are the murder of Kato Mo, who died in a gang fight outside a brothel in 1986; the 1994 murder of Talal Assad, a suspected drug dealer bashed to death by a rival drug trafficker; the shooting death of Ali Ghazzawie; and the 1988 shoot...

Campaign to uncover the wrongly convicted

Malcolm Brown

ESTELLE BLACKBURN, still glorying in the achievement of having had two homicide convictions overturned in her home state of Western Australia, believes her battle has barely begun.

She fought for a decade to secure the exoneration of John Button and Darryl Beamish, who were convicted in the early 1960s for crimes committed by the serial killer Eric Edgar Cooke.

Ms Blackburn, 57, reduced her ... in 1992, in which law students studied doubtful cases as part of their degree courses, supervised by lawyers working pro bono.

University "innocence projects" have been established at the University of Technology, Sydney, Newcastle University and in other states. A fledgling project has just been established in Western Australia. Ms Blackburn, a committee member of the Innocence Network, believes there is greater scope for co-operation.

Pell plans fidelity oath for principals

From Page 1

"sexuality and life issues" through formal courses and seminars, and measures to bring in to the fold young people inspired by next year's World Youth Day.

Cardinal Pell has taken an intense interest in Catholic education, ordering the rewriting of the religious education curriculum, and aiming to turn around Catholic thinking that faith is caught, not taught.

The oath has symbolic value as a public commitment to the moral teachings and identity of the church and is not an attempt at control, the archdiocese says.

But a recent Vatican push to institute an oath for theologians in the US was greeted as an attack on academic independence and an attempt to impose tighter doctrinal controls over education institutions connected to the church.

One critic of the archdiocese's plan says it contains "shades of the Opus Dei", the Spanish-founded conservative church movement that achieved notoriety as the villain of the fictional bestseller *The Da Vinci Code*.

Writing for the online magazine *Catholica*, a Sydney priest, Father Dan Donovan, said the plan needed a serious rewrite and failed to take note of the "infiltration" of Opus Dei and the Neocatechumenal Way, a lay movement that heads the turbulent Redfern parish.

In addition, the plan lacked a suitable process for "critiquing structures and providing just outcomes, and was directed to the needs of clergy and not churchgoers", he said.

"There must be developed a listening hierarchy who are able to connect with the broad masses of the faithful and their issues, rather than endorsing the agenda of the various movements."

The Sydney Auxiliary Bishop Julian Porteous said the oath would act as a reminder to educational leaders of their role in promoting church teachings.

"It's not about control," he said. "The oath gives greater clarity to the importance of the role of prin...

Local history is rock solid

LOCAL engineer Wally Mills will bring to life a little-publicised feather in Cooma's historical cap this week to mark National Engineering Week.

At two venues on Thursday, Mr Mills will tell the story of a group of people who have a place in engineering history after helping to develop rock bolting into a world-recognised engineering discipline.

"It's entertaining, because I'm talking about people, not just about things," said Mr Mills.

"Some of these people will be well-known to the Cooma community.

"I want to keep this history in front of people because I think it's something that can be inspiring for today's generation."

Engineering History in Cooma Rock is at the Cooma Library Annex on Thursday from 1pm and at the Snowy Hydro Information and Education Centre from 5:15pm.

The presentation includes slides and samples and will last about an hour.

For more information contact Wally Mills on 6452 7321 or 0403 132 825 or David Byrne on 6450 1750.

C-M Exp... Tue 21/8/07

23/8/07 C-M Exp

Local engineer Wally Mills will revisit an engineering feat of the 1950s today in a lecture intended to inspire today's problem solvers.

World first revisited

JULY 1956: a large rock fall interrupts excavation of Tumut 1 underground cavern.

It would take a talented group of local scientists and engineers to remedy the damage, but in doing so they would step outside the square of 1950s engineering theory and do something completely different.

The solution was a world first, right at our doorstep.

"Previously rock bolts had been used to just pin the exposed rock back to more solid rock behind, but what the Snowy Mountains Scheme people developed was the concept of creating a self-supporting zone of rock around the excavation by reinforcing it with rock bolts," said local engineer Wally Mills.

According to Mr Mills, the development has gone on to be used in excavation works around the world, saving time, money and lives.

"It has saved enormous cost by not over-excavating, it has meant the work has proceeded faster and it has also meant a much safer working environment for the miners."

Mr Mills will bring the story of the feat to life at a lecture today to mark National Engineering Week and inspire the problem-solvers of today.

The lecture - Engineering History in Cooma Rock - was well-received by a Sydney audience in June and prompted organisers of an event in Hobart to invite Mr Mills to speak in October.

Cooma residents will have the chance to hear the tale at the Cooma Library Annex from 1pm or at the Snowy Hydro Information and Education Centre from 5:15pm.

APPENDIX G – PERSONAL CORRESPONDENCE WITH B. BLEHM

Personal correspondence dated 4 & 5 May 2008 and photographs from Mr Berle Blehm, USA, (2008), required, as the contractor's supervisor, to correctly install and grout the SMA- approved rock bolts, according to SMA's detailed and specified requirements, in the major tunnels and caverns of Tumut underground power station, 1959-61.

ROCK BOLTING INSTALLATION BY CONTRACTOR AT TUMUT 2 POWER STATION: PERSONAL CORRESPONDENCE

From: Berle Blehm
Sent: Sunday, 4 May 2008 1:20 AM
To: Wally Mills
Cc: Berle Blehm
Subject: Rock Bolts

Hello Wally, ...I hope all is well with you and family there in Cooma. It is times like these that I wish that Australia was not so far away as both Kay and I are ready for another trip to your young country.

I have found the pictures of T-2, and gone thru them and I believe I have more but don't know where they are but will find them. The pictures that I have were all taken by Bob Miller, who was the Chief Engineer for Kaiser Perini Morrison and Raymond who were the Contractors for the T-2 Project that consisted of the T=2 Ponds Dam, Headrace Tunnel finish size 19Foot Concrete Lined, Tumut -2 Underground Power Station and the 19 Foot Tail Water Tunnel that came out at the Township of Sue City, which is currently under water. Miller took Project Progress Pictures of the project as they progressed thru the Excavation and Concrete Phases at all locations. These photos were shared by Miller with Snowy Mountain Authority as time progressed. I was told by Miller in 1999 that these photos you are to receive are ones that were not given to SMA, and are in random photos he had made for his own use. Miller said that he was going to "Throw These Photos Away" as they were of no value to him any more. I quickly told Bob, "Give them to me, as I would greatly appreciate them!". Sometime in 2000 Bob found them and sent them to me. So I think I can honestly say that you and I have Bob Miller to thank for the photos.

I have gone thru and scrutinized the photos, of which are atleast maybe 100, and removed all that have Rock Bolts in the photos, but in some one has to look very carefully to see the Rock Bolt Plates, the White Plastic Tubes used for Grouting and the Rock Bolts themselves protruding from the Machine Hall Walls, Tunnel Arches and Etc. The Rock Bolts were set as close as possible to a 4Foot Square Pattern in the Machine Hall Walls, and in the Arch's of the Machine Hall and the Transformer Walls, as well as in the Arch or Roof of the Surge Tank. Going back into memory, and the notations that I had made in my fathers Construction Binder that had some of these pictures, I noted that the Rock Bolts were 3/4 Inch and 1 Inch Bolts. The Rock Bolts in the Machine Hall, Transformer Hall, Surge Tank, and in the "Bottom End", which consisted of Rock Bolts in a Pattern (as close to a pattern as possible) on 4 foot centers around the bottom of the Surge Shafts at the Surge Shaft Valve Level. This is what we called the Bottom End is where I did all of my work from Excavation to Finish Concrete of the Draft Tubes, Branch Tunnels, 30 Foot Tail Race Tunnel, Transition from 30 Foot to 19 Foot Tailrace Tunnel, Excavation and Concreting of the two Surge Shafts. I was the one who did the work once JD Kimsey, who was the Power House Superintendent decided what he wanted done and in what sequence. (I thank the lord that I did have the experience to do what I had to do as I was a very young man then, 26 or so of age, but I started in Tunnels with and for my father at the tender age of 16 in 1948).

I will try to identify all of these photos and where the Rock Bolts are located. In the pictures Small Square Images in the Tunnel Arch's (Roofs to most people), Tunnel Ribs, (Walls to some people) one has to look very carefully but one can see the White Tubes used for Grouting Purposes protruding from the Rock Bolts, mainly in the Arch Sections, but around the Rib at the Surge Tank Valve Section, at the Intersection point of the Draft Tubes, the Two Surge Shafts and Branch Tunnels in the "Bottom End" of the Power House where I worked. The White Tubes can be seen in the Arch Section of the Transformer Hall and in the Machine Hall Arch.Rock Bolts can be seen in the Headwall of the Machine Hall above the Assembly Bay and Workshop at the end of the Machine Hall.

The Installation of Rock Bolts in the 34 Foot Excavated Tail Race Tunnel were mainly at random and placed to hold the various large sections of rock that had indications that it might slip and fall at a later time, and also pin the rock in place as tightly to the surrounding rock as possible, and to try to seal the seam of the rock to hold back the AIR SLACK that would take place in the seams at the outer edges of the rock. Many times large rocks that we had Pinned, would last maybe three or four Shootings of the Tunnel Face (as the tunnel progressed) and we would start the Tunnel Mucking Phase, and find the this same rock we had previously Pinned, had broken loose and was hanging by to the Rock Bolt that we had installed to pin it back. We then would cut the Rock Bolt with an OXY Torch, and proceed with the work.

Rock Bolts were also used to Pin Back to the Rock Tunnel Arch Supports, such as in the Machine Hall Arch at the Control Room Location. At times Rock Bolts were also used to Hang and Install Wire Mesh like material (Cyclone Fencing Material) for protection of small rocks falling from high in the Arch Sections of the Machine Hall and the Transformed Hall. One must not think that the Rock Bolts will be the final answer for the Tunnel Supports Underground, as they are not. They have their place where they can be used, but Tunnel Steel Arch Supports are needed in ground consisting of Conglomerate Materials, where the Anchoring of the Rock Bolt is not able to be attained. Luckily, the Under Ground Power Station did not have this type of Rock Material of which the Contractor was very fortunate.I can see where Rock Bolts can be used, but as quickly as possible a Form of Shot Crete can be used to Seal The Air from the Rock. This Shot Crete Coats the Rock and very little Air Slack can take place.(In the Wine Country here in the States in California, huge Caverns are being excavated and Shot Crete is being applied for mainly sealing off air. These Caverns maintain an air temperature that does not fluxuate more than 10 degrees the year around)

George "Okie" Blehm was a person from what we call 'The Old School", and was a Hard Rock Miner in 1935, when they used the old "Column and Bar" method of drilling. One would set a 4 inch Pipe from the Arch to the Invert (Floor to some people), and then set a 4 inch piece of Pipe horizontal with a 'Collar Attachment" secured to the Vertical Pipe. On this they would Man Handle a "Drifter", more commonly known as a Air Drilling Machine. 1 Inch Bolts with 1 1/2 Nuts would secure all of these items together and then hooked to Air and Water. Instead of the long Shells they had later used for the Drifters to moved back and forth on when drilling, the

ROCK BOLTING INSTALLATION BY CONTRACTOR AT TUMUT 2 POWER STATION: PERSONAL CORRESPONDENCE

Miners started with a 2 foot Drill Steel, drilling the Tunnel Face, and changing Steel every tow feet in length graduated up to maybe ten feet, sometimes 12 feet depending on the size of the Tunnel or Drift that they were working in. Large Tunnel they perfected what is known as a "Drill Jumbo", with as high as 12 to 16 Drifters. This included the Arch Machines, Wing Machines and the Lifter Machines. Wing Machines were on the Center Deck, who drilled the Cut, Reliever Holes as well as the Ribs Holes. The "Lifter Machines" drilled the Invert, or Floor Holes as well as the Bottom Rib Holes. I was fortunate that I started on the Out Side Lifter Machine as a "Chuck Tender" which the Aussies call "An Off Sider" in Tunnel Slang. This is where I got my Drill, Shoot and Muck Experience. It didn't take me very long to realize that Mining was something that I would not rather do, so I ventured into Concreting of Tunnels as early as 19 years old. I have done mostly Concrete Work in Tunnels from, 1951 until 1972 when I did my last job in West Australia Concreting the Tunnels on the Ord River Dam.

I will never forget the junction of Surge Tank, Draft Tube N0 5 and N0 6 and the Branch Tunnel, as here is where I lost a man in 1959. Ernesto Vecchiatto Age 26, from maybe 1/2 inch of Jelly in the bottom of a Line Hole being struck with a Hot Bull Point of a Jack Pick. He was one of two fatalities of the Power House. Gary Adams was the other.That Picture of the NO 5 Draft Tube shows the Steel Support in place and later we placed Wall Plate with Steel Supports in this Area to help support the ground as the Shaft was to be "Caved In" from top down and the bearing of weight was to be carried by the Draft Tube Rock and Supports, as well as the Rock Bolts. This is where I lost a man and I have never forgotten that incident.

This is enough for now, and I will take some of these photos to the Drug Store (Chemist) and have copies made. I will get them to you as soon as I can.
I hope I have been a help to you and your project and I will send more information later.

I will close, and you should receive this on Sunday Morning of the 4th of May. I will be 76 on the 6th.

OK, Cheers to you for now,

Berle Blehm

ROCK BOLTING INSTALLATION BY CONTRACTOR AT TUMUT 2 POWER STATION: PERSONAL CORRESPONDENCE

From: Berle Blehm
Sent: Monday, 5 May 2008 2:20 PM
To: Wally Mills
Subject: Pictures

Wally,............Hope all is well. I will put in the mail tomorrow the pictures of the Power Station. I have made notations on the back side of the photos and I have tried to show you where all of the Rock Bolts are in each picture. Some I have circled, others I have made notations on the back. I hope that thee are of a help to you, and I had these made for you and they are bigger than the ones that I have, and better pictures. I think I have a few more somewhere, and I will look for them and if I do find more I will send them on to you.

It will be impossible to talk with OKIE Blehm, as he passed away Dec 30, 1994 at 85. I am the only one left that was with the Underground Mob that was there, and if I had been as old as the other BLOKES from the States, I too would be gone. I was fortunate to have been able to work with the OLD Timers who were in the Tunnel Business. What most of the companies are using now are Mining Machines that will cut a full circle, set Segment Sets to push against and also be the Ground Carrying Section of the Tunnel to keep the ground from falling into the tunnel. I have been fortunate to have Operated three of these machines, and they are quite interesting to say the least. They have just about taken the place of the Drill Jumbo in most cases. Currently Theis Brothers and some other companies have a Mining Machine working in Brisbane and this tunnel is for a High Way Tunnel to relieve the traffic in Brisbane down town. They were to Launch this Machine (Start Excavating) the 15th or so of December last year. This machine is 35 feet in Diameter I believe. It is a big one as a picture of it was in the paper.

When we had to Grout a Section of Rock Bolts, we would attach a Plastic Tube with Wire to the Anchor of the Rock Bolt. Insert the Rock Bolt to the full length of the drilled hole, set the Anchor so that the Bolt would stay in the Hole. The Plastic Tube HAD to attached to the Anchor, not the Bolt. We would remove the Nut holding the Bearing Plate, remove the Bearing Plate, and place a HAND FULL of Mortar on the Bearing Plate , put the Bearing Plate onto the Rock Bolt, and shove the Bearing Plate up tight to the Rock Face, place the Nut on and tighten the Bolt to the proper Torque. We would take Mortar and smear it all over the Bearing Plate and Rock to help seal the area between the Rock and the Bearing Plate. We used what Kimsey called Long Nuts, and the Long Nuts were actually double Nuts with double the Thread Area as it always happened the Threads would strip out of the Nut when it was Torqued to the required PSI. So instead of using the Normal Nut, we used a Double Length Nut for the additional threads. By doing this, we had atleast 95 percent satisfaction of a properly torqued Rock Bolt. We would Water Test these Bolts that were to be grouted at a later date to see if they would hold water. Some held water, some didn't.

When we prepared to Grout Rock Bolts, we would first Water Test the Holes and the Plates to make sure they were sealed and they would hold Grout and the Aluminum Expander. This was water and cement and we mixed it as stiff as we could, but still fluid enough to HAND Pump it thru the Pump and the Grout Tubes. The reason we

used the Hand Pump was that we could feel the build up of pressure within the Rock Bolt Area, and the grout had a good return on the Return Tube, we would crimp off the Return Tube and Hand Pump until we had a substantial pressure and could pump no more Grout, we Crimped the Injection Plastic Tube and went to the next Rock Bolt. During the Grouting Operations we would watch for Grout Appearing and leaking from a Rock Seam. Some times we had this happen, and most generally we did not have a Leaky Seam, but we had to watch for this to happen and then had to try to stop the Leak with Mortar or Rags stuffed into the crack. If we could not stop the Leak, we had to pull off of the Rock Bolt, wash the Return Tube and go to the next Rock Bolt. We then would come back at a later time and try to Grout this Bolt as the Motor, Rags and the Pure Cement would set up and a lot of times Seal off. When we returned to this Non Grouted Bolt, we would hook on to the Return Tube which the end of the Tube in the hole went to the Anchor of the Bolt. The rest of the Bolt Hole was Grouted, but not the 'Fisher" or seam of which was leaking on the initial try to complete a Grouted Rock Bolt. The Grout would be pumped to the Anchor of the Bolt,thru the Original Return Tube, as the Initial Injection Tube was Grouted Off and the only way we could get grout to the Anchor and the Fisher Seam was thru the Anchor Area. We were quite successful Grouting Bolts in this manner. I firmly believe that when we grouted off a Seam that had leaked, we were sealing off a seam that would later have created Air Slack between the Rocks, and could become a Rock falling from the Arch or Rib, and being held only by the Rock Bolt itself. By getting Grout into the seam, you stopped the Air Slack at some degree, if not completely.

Rock Bolting when drilling UP at an angle, the Rock sometimes broke away and slid down the Drill Steel to the Air Drifter Machine. Sometimes it would break into large pieces, and this of course could be very dangerous. At all times all the Miners were watching the Drilling as most anything could happen.

I will close this for now and go to bed. I have so many projects going that I don't know which one is going to get done next. I finish one, and get two more. But one thing I know I will be 76 on the 6th. It is starting to tell on me too.

Take carte, and I hope this has help you in your project.

Berle.


695
GRAVEYARD
DAY
SWING
TOTAL
MON 660 612 594 1866
TUE 612 756 342 1710
WED 630 702 846 2178
THU 630 684 738 2052
FRI 576 570 792 1938
SAT 936 924 920 2780
TOTAL WEEK 4044 4248 4232
GRAND TOTAL 12524
RECORD SHIFT 936 YDS
WALKER Schneider
RECORD WEEK 4248 YDS
WALKER PIPER
TOTAL TO DATE 79,729

Mgr. Foreign.
Sir William Hudson
Red Fulton - Project Mgr T.2
Bob Patton - ? Yes, T2 Resident Engineer
George "Okie" Decker Underground ^later Supt. T.2

1960

Machine Hall. This is what is called a "Top Heading". Note White Grout Tubes — 4' Centers. Truck on left is what we used for Water testing and Grouting of Rock Bolts.

Walgreens (17) 05/03/06

Machine Hall
Tumut 2 Project

June 14, 1959

Concrete Pour Placement on Tail Race Tunnel. This Pouring Rig created the best Underground Tunnel Concrete Placing Record — which still stands today. This was in 1959-1960.

Walgreens (17) 05/03/06

Tail Race Supt. Office
Tumut 2 Project.

1961

APPENDIX H – SIGNS

1 Two existing signs to explain the Site; one of text and the other of a drawing of the final form of the SMA rock bolt.
2 Information Plaque for the consideration of the Plaquing Sub-Committee.

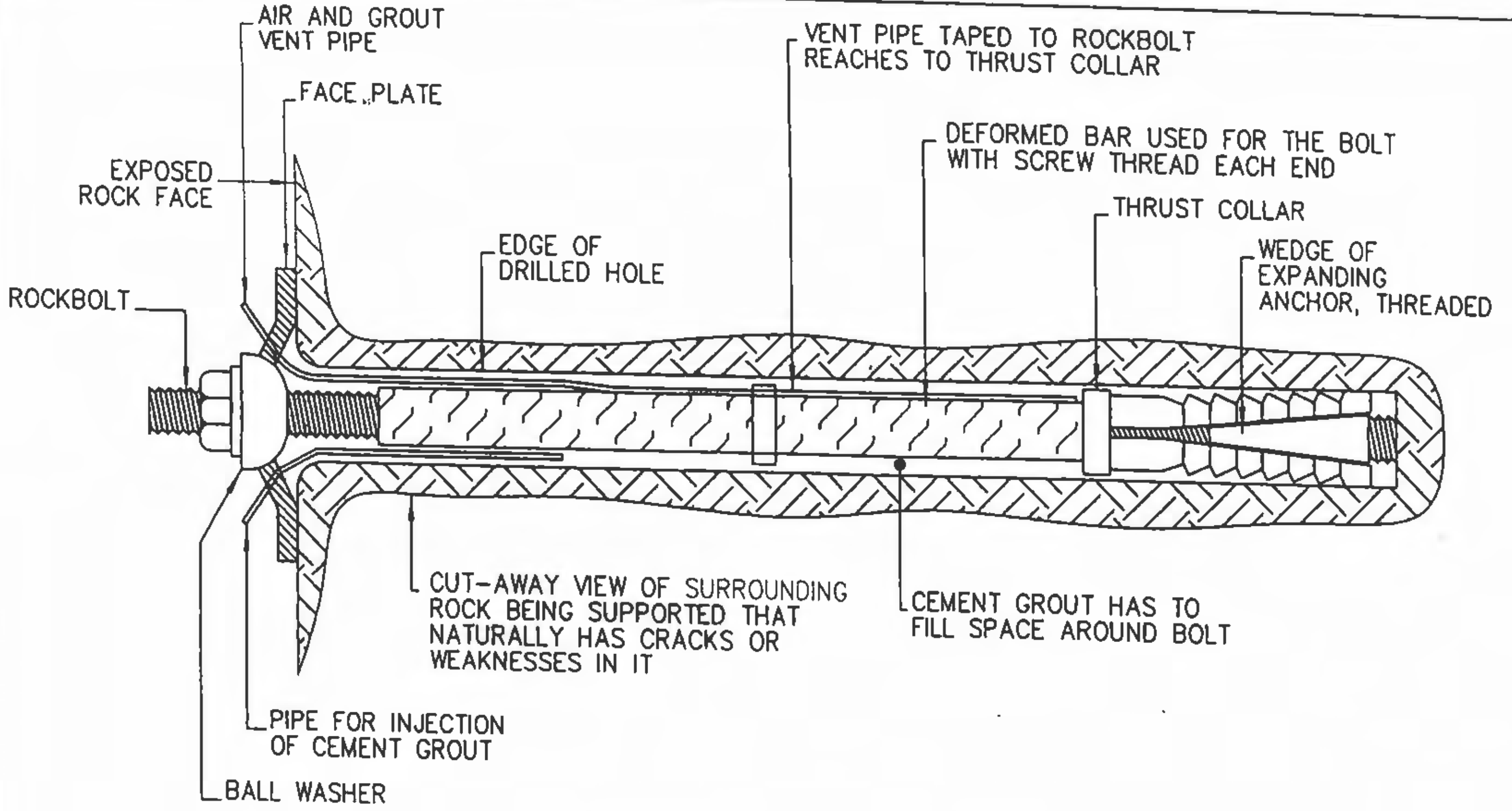
ROCK BOLT EXPERIMENTAL SITE

Lambie Gorge is the site where Snowy Mountains Hydro-Electric Authority tested unique designs of various rock bolts during the 1950s. The rock bolts developed were used to stabilise the exposed rock in underground excavations. It was important to develop an anchorage that was as strong as the bolt itself.

In actual use, the rock bolt (up to 4m long) is inserted quickly into a drilled hole, anchored and tensioned against a surface plate to compress the surrounding rock. When rock bolts are in a pattern across an excavation, the clamping action creates its own arch support. For permanency, rock bolt holes are then immediately injected with grout to bond the rock bolt and rock as one. This also stops the possibility of corrosion of the rock bolt.

At this site, 'pull-out' tests guided the rock bolt development, resulting in safe tunnelling for the Snowy Mountains Scheme. The design and application soon became a world-wide engineering practice.

ROCK BOLT EXPERIMENTAL SITE



START WITH HOLE DRILLED STRAIGHT INTO EXPOSED ROCK
ROCKBOLT OVERALL LENGTH UP TO 4 METRES

TYPICAL GROUTED ROCKBOLT IN-PLACE
FOR SELF SUPPORT OF UNDERGROUND CAVERNS & TUNNELS IN HARD ROCK

W B Mills, COOMA June 30, 2005

PROPOSAL

ENGINEERING AUSTRALIA INFORMATION PLAQUE

ROCK BOLTING DEVELOPMENT SITE

When tunnels and caverns in the earth's crust are designed by engineers, rock bolting is required universally to now make the exposed rock self-supporting and to prevent rock pressure behind collapsing the hole. The benefit can be made to last even in water carrying tunnels.

The rock bolting design requirements and rock mechanics theory development by a select team from the Snowy Mountains Hydro-Electric Authority utilised this Site for rock bolting experiments between 1956 and 19-62. The Site represents a window into the advances in technology used for tunnelling.

Rock at this Site is like that encountered for the 134km of tunnels and underground hydro-power stations of the Snowy Mountains scheme, mostly hidden from view. Rock bolting made tunnelling much safer, faster and less costly than earlier tunnelling methods. The practice immediately spread worldwide and continues with little change today.

The Institution of Engineers Australia
Monaro Group, Cooma, 2009